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RUDIMENTARY TREATISE

ON THE

DRAINAGE

OF

TOWNS AND BUILDINGS:

SUGGESTIVE OF

SANATORY REGULATIONS CONDUCIVE TO THE HEALTH OF AN INCREASING POPULATION.

BY G. DRYSDALE DEMPSEY, C.E.,

Author of "The Practical Railway Engineer," and of the "Rudimentary Treatise on the Drainage of Districts and Lands."

REVISED AND GREATLY EXTENDED: WITH NOTICES OF THE METROPOLITAN DRAINAGE, THAMES EMBANKMENT, AND WATER SUPPLY SCHEMES.

FOURTH EDITION.

LONDON:
VIRTUE AND CO., 26, IVY LANE,
PATERNOSTER ROW.
1867.

PREFACE.

Two volumes of the *Rudimentary Series*—"The Art of Draining Districts and Lands," and the work now submitted to the reader—relate to the subject of drainage generally, with water supply as an auxiliary or necessary contingent: the removal of surplus waters and refuse on the one hand, and the supply of pure water on the other. The one volume applies to *Districts* and *Lands;* the other to *Towns* and *Buildings*.

It becomes necessary to remark in this (the *Third*) Edition of the present work, that when the late Mr. Dempsey prepared the *First* and *Second* Editions, the whole subject of the *Drainage of the Metropolis* was in confusion. The most eminent engineers were in conflict as to the best mode of attaining the desired end. The plan eventually adopted, and now (1865) in progress, differs from that which Mr. Dempsey and many other engineers recommended. This, of course, is not conclusive as to the relative merits of the different schemes. Who were right and who were wrong, in these speculations, we shall not know for many years to come; until the Intercepting Main Drainage plan shall have had a fair trial by long-continued working. On this account it seems desirable to leave Mr. Dempsey's calculations and deductions in their original form; because they embody, or rather illustrate, one particular principle of Drainage, which may probably apply to many other large towns, irrespective of its adoption or rejection in the metropolis. By greatly enlarging the APPENDIX, space has been found for a succinct account of all that has been done in relation to the Main Drainage Scheme since the publication of the Second Edition of this volume, in 1854.

Plain facts are stated, without any prediction concerning the degree of success that may attend the operations now in progress. In a later portion of the APPENDIX, relating to the *Utilisation of Sewage*, it will be seen that this important question remains nearly in the same unsettled state as when Mr. Dempsey prepared the Second Edition. Much has been said, and much written; but the world has yet to learn whether the sewage of the great metropolis is to be rendered available as an agricultural fertiliser. We may here refer, for fuller information on this important subject, to another volume of this Series (Vol. 146), Mr. Robert Scott Burns' Rudimentary Treatise for Students of Agriculture, called, "Outlines of Modern Farming;" the fifth volume of those Outlines relates to Utilisation of Town Sewage, Irrigation, and the Reclamation of Waste Lands. The *Embankment of the Thames* being now recognised as an important feature in the Main Drainage Scheme, we have deemed it useful to devote one portion of the APPENDIX to this subject.

Another volume of the *Rudimentary Series* * treats generally of Water Works, and the Supply of Water to Towns. It has been considered only necessary here, therefore, to notice briefly in the APPENDIX one or two advances which have been made between 1854 and 1865, in improving the systems sketched in the text by Mr. Dempsey, especially in regard to London and Glasgow.

LONDON, 1865.

* "A Treatise on Waterworks for the Supply of Cities and Towns; with a Description of the principal Geological Formations of England, as influencing the Supply of Water; details of Engines and Pumping Machines for Raising Water; and description of Works which have been executed for Procuring Water from Wells, Springs, Rivers, and Drainage Areas."—By Samuel Hughes, F.G.S., Civil Engineer. Vol. 82***

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DIVISION II.

DRAINAGE OF TOWNS AND STREETS.

SECTION I.

Classification of Towns according to Position and Extent.—Varieties of Surface, Levels and Inclinations.—Application of Sewage Manure.—Metropolitan Sewage Manure Company.—Methods of treating Sewage.—Magnitude of London Sewers.—The Fleet Sewer.—Metropolitan Commission of Sewers.—The Tunnel Scheme.—Great London Drainage Bill.—Messrs. Stephenson and Cubitt's Evidence.—General Board of Health.

194. ACCORDING with our definitions (Part I. p. 1), we propose to treat of the *supply* of *water* to *towns* and *buildings* as a branch of the general subject of *Drainage*, since the purposes of the art cannot be effected without an adequate and regulated supply of water by a combination of natural and artificial agencies, the extended control over which constitutes the purpose of water-supply for all highway, manufacturing, and domestic uses.

195. The means of obtaining water for towns, and of conducting the drainage matters from them vary, mainly, according to their position with reference to the sources of water; and, in a subordinate degree, according to their superficial extent. The sources being those already enumerated in our First Part, viz. rivers, rains, and springs, the command of one or more of these will be presented as the most economical means of deriving the necessary supply for each town under consideration. Towns situated on the banks of tidal rivers, or in near proximity to them, may be

usually sufficiently supplied from these sources, unless some parts of the district extend upward to such elevation above the river-level that the raising of this supply requires expensive artificial power: in which case springs at higher levels may be advisably resorted to, or the drainage waters from superior lands may be so conducted as to assist the supply. Towns which are far distant from rivers are commonly entirely dependent upon springs or drainage waters for their artificial supply.

196. The refuse matters to be discharged from towns and buildings,—consisting of the disintegrated materials of street paving and roads; of superfluous rain water; of excrementitious matters, solid and liquid; of the waste products of combustion; of the refuse of animal and vegetable substances; besides the various waste matters used in manufactures,—require arrangements of different kinds to be provided with regard to the purposes to which these matters may be usefully applied. For such discharges of these matters as are to take place through subterranean channels, one principle is, however, common to all, viz. that the receptacle to which they are conducted must be situated at a level somewhat lower than that from which they are forwarded. The arrangements for this purpose will, therefore, be varied according to the nature of the site of the town. If this be low in relation to the surrounding country, and level, the refuse may be indifferently collected within or without the town, with, however, the advantage in the latter plan of avoiding such exposure of the decomposed matters as tends to pollute the atmosphere, and at the same time saving distance in the transfer of such portions of those matters as are destined for agricultural uses. If the site of the town be a valley with lower ground in the midst of it than is found anywhere without its limits, the readiest point of collection will be the lowest level in the town itself at which the drainage can be united, and artificial power will be required to distribute such matters as are intended for agricultural purposes around the higher ground outside.

From towns which occupy elevated sites, having lower lands around them, the refuse matters and drainage waters should be conducted away at once; or, if found necessary to collect them, a point or points should be selected for this purpose altogether beyond the limits of the town itself.

197. In the several cases here supposed, the question of disposing of the refuse matters should be treated without any reference whatever to the presence of a river through or contiguous to the town, except upon the single consideration that such river, being in all probability situated at the lowest level of the site, may afford facilities, after the refuse has been collected in reservoirs near its banks, for its conveyance in suitable barges or vessels towards the higher lands for which some portion of this refuse is ultimately destined. Former practice in the art of town-draining has indeed regarded the one question of river or no river, as the grand determinal one for the disposal of drainage and refuse matters. How to get rid of the animal ordure created within the walls of a town, was formerly deemed to be satisfactorily answered provided a river flowed beneath, and offered a tide to wash away in boundless wastefulness those matters which, properly applied, will endow barren lands with the richest fertility.

198. Although reluctant to dwell upon the trite subject of the *importance* of draining, we claim attention to this great leading principle in the drainage of towns and buildings, viz. that the ultimate economy of the art comprehends two distinct purposes, whereof the second—the disposal and utility of the refuse matters—is little less in importance than the first—the discharge of these matters from the dwellings and highways of men. And the accomplishment of this second purpose involves the beneficial appropriation of refuse matters so as to make them actually productive, and avoid interference with those healthy uses of inland waters for which they are properly adapted. In illustration of this principle we will endeavour to estimate the value for agricultural purposes of the excrementitious matters

flowing from a town, from which estimate the pernicious effects of discharging those matters into the courses whence the supply of water is derived for the several uses of the population may be readily inferred.

199. The value of manures as promoters of vegetation is known to result from their possession of the essential element, nitrogen, in the form of ammonia, with the subordinate properties of alkalies, phosphates, and sulphates. Now, the experiments of Boussingault and Liebig have furnished us with the means of estimating the quantity of nitrogen contained in the excrements of a man during one year, at 16·41 lbs., upon probable data, and also that this quantity is sufficient for the supply of 800 lbs. of wheat, rye, or oats, or of 900 lbs. of barley. "This is much more than it is necessary to add to an acre of land, in order to obtain, with the assistance of the nitrogen absorbed from the atmosphere, the richest crops every year. By adopting a system of rotation of crops, every town and farm might thus supply itself with the manure which, besides containing the most nitrogen, contains also the most phosphates. By using, at the same time, bones and the lixiviated ashes of wood, animal excrements might be completely dispensed with on many kinds of soil. When human excrements are treated in a proper manner, so as to remove this moisture, without permitting the escape of ammonia, they may be put into such a form as will allow them to be transported even to great distances."* Making reasonable allowance for the reduced quantity produced by children, we shall be safe in assuming the nitrogen thus resulting from any amount of population to be equal to the supply required for affording 2 lbs. of bread per diem for every one of its members! Or assuming an average of 600 lbs. of wheat to be manured by each individual of the population of London; and taking this at two millions, for a rough calculation, the manure thus produced is sufficient to supply the growth of wheat of a total weight of 1200 mil-

* Liebig.

lions of pounds, or 535,714 tons. The total manuring matters, solid and liquid, produced in a town, allowing for those which are produced in manufactories and sewage water, are probably equal in weight to one ton annually for each member of the population, or two millions of tons produced in the metropolis.

200. That this vast quantity of manure should be made available for agricultural production is a principle which cannot be denied, and which is properly limitable only by the consideration of expense as weighed against the value of the results. The expense will be made up mainly of three items, viz. of the *collection*, of the *raising*, and of the *distribution* of the refuse matters. The collection being an item common to all methods of disposal, will not be chargeable entire in any comparative estimate, but as modified by the peculiarities in the collection of which the plan is susceptible. The cost of raising is of course wholly chargeable to a system of artificial dispersion, as distinguished from the prevailing modes of self-discharge into low channels, but the former system will be debited only with the excess of expense (if any), beyond that incurred by the present methods of distributing the manuring matters for use upon the land. The cost of each of these works, however, may be reduced to a minimum by skilful arrangements, and our experience is yet insufficient to enable us to determine these with that precision which further practice will secure, or to estimate their total with the exactness necessary for forming a just comparison between the present and the proposed methods.

201. In a subsequent part of our work we propose to consider the items of cost in carrying out an efficient system of town-drainage; being satisfied, at this stage of our subject, in declaring the fundamental principle that the refuse of a town, including not only excrementitious, but all other waste matters and sewage, is far too valuable to be thrown away; and that the question of its appropriation should be made dependent only upon rules of a liberal

economy, which ought, moreover, to be severely criticised before admitted to practical consideration.

202. The palpable inference from this principle is, as already stated, that the contiguity and position of a river, with reference to a town, have no necessary connection with the arrangement of its drainage beyond the facilities which may be thus afforded for the passage or subsequent conveyance of the sewage matters for their ultimate disposal. For it is quite certain that no correct general views of town-drainage can prevail while we continue to regard a river as the natural and suitable trunk sewer into which all collateral and main courses of brickwork are to discharge their fœtid contents, which, according to the state of the river, are either immediately spread upon its banks to contaminate the air of the town, or duly infused in its waters, to be afterwards exposed with the same vicious effects.

203. From the principles here laid down, it will be understood that in the twofold purposes of the drainage of towns, viz. the supply of water, and the discharge and disposal of the refuse matters, the relative levels of the town, with the adjacent districts, and of the several portions of the town with each other, are the main considerations upon which the peculiar methods to be adopted in each case are determinable; but it will also be evident that, generally, those surfaces which are the most favourable for an economical water supply are the least so for the ready disposal of refuse matters, and the converse is equally true; those surfaces which present facilities for dispersing drainage-matters being commonly the least accessible to water.

204. Thus the flat districts on the margins of rivers and inland streams of adequate capacity are the most favourable sites for towns for the supply of water, but for drainage they are the least so; since the main channels or sewers are required to be laid at low levels, and the raising of their contents for use upon the neighbouring lands, which are probably much higher, becomes a very expensive process. On the other hand, a town on a hill-top is the most readily

and cheaply drained; but its supply with water, whether from springs, rivers, or surface drainage—all at lower levels —is a work of great and constant cost.

Let us consider the several kinds of site which towns may occupy.

205. *First.*—A plain or flat surface, with surrounding country of similar character. *Water* from rivers, springs, or from the surface of lands in the neighbourhood. Artificial power will be probably required to raise the water, however derived. The *drainage matters* must be conducted into one or more main sewers, and raised by artificial power for dispersion upon the land.

206. *Second.*—A plain or flat surface, with surrounding country rising from the town. Unless well situated with regard to a river, the supply of *water* will probably be the most economically obtained from springs on the hills, or from the collection of the waters which accumulate upon their surface. The *drainage matters*, if destined for the higher lands, should be generally conducted by mains towards the outskirts of the town, and the question of levels will evidently derive additional importance from the necessity of raising the sewage to levels naturally above that of the town itself.

207. *Third.*—A plain or flat surface, with surrounding country falling from the town. The supply of *water* beyond that derived from wells and springs will require artificial power, while the *drainage matters* may be collected in main sewers, and, in all probability, dispersed without any application of power, by the force of their own gravity.

208. *Fourth.*—An inclined surface on the side of a hill. *Water* will be derivable, probably, from several sources. If a river flow at the base of the site, the lower parts of the town will be most economically supplied from it, while for the higher the surface water from lands above or springs will be the most readily available. The general system of collecting and distributing the *drainage matters* will be chiefly dependent upon the localities where they are in-

tended to be ultimately disposed of. If these be on the lower part of the hill, the method will be very simple, requiring only that main sewers be laid at the base of the town, from which the sewage may be distributed without any application of artificial power. But if the disposal of the sewage be inevitably desired on the lands above the town, the site constitutes one of the least favourable for economical drainage, which will require a constant expenditure of artificial power.

209. A river-valley and a hill-top will evidently present a repetition or duplication of similar features to those here described, the only limitation in the resemblance being that, in the case of a town on the summit of a hill, the water supply will, most probably, be derivable only from lower sources by artificial power.

In these sketches the general superficial features of the site are of course only referred to. Intermediate undulations which may exist will affect the determination of the details of any arrangement of channels designed for serving the drainage of the town.

210. With reference to the artificial power which may be required for the supply of water, or the discharge of the drainage matters, if a tidal river can be commanded, it becomes a question of the highest importance whether this cannot be, and, if so, in what way, made available as a source of the power required. And another question deserving the most attentive consideration is, whether the ebb tide may not be rendered efficient in aiding the discharge of the sewage where the fall is inadequate to insure its self-discharge.

211. As a general principle in town drainage, however, it should be so arranged and conducted as to require no artificial supply of water. The surface water should always be made sufficient to carry away all refuse matters, solid as well as liquid. Two reasons exist for this: first, the economy of the water, which in many cases is a paramount, and in all should be a leading, consideration; and, secondly,

the dilution of the sewage with any unnecessary liquid involves more capacious arrangements for its diffusion, and in most instances an extravagant amount of power to raise it.

212. The utmost economy of water for draining purposes can be secured only when a sufficient inclination in the sewers can be obtained. The methods of making a fall the most effectual are, therefore, deserving of the most careful attention in every scheme for town-drainage. The application of the tidal waters for assisting the discharge of the sewage can consequently be entertained only with reference to the principal main sewers at the lowest level, and with such adaptation, if practicable, as will admit the subsequent separation of the proper sewage matters from the water thus introduced to aid their progress and discharge.

213. Although the rules here suggested should be kept in view as leading objects in all arrangements of town-drainage, they will in many cases be admissible in part only, owing to the reference to existing works which is imposed upon us. Thus, in all towns for the attempted drainage of which some arrangements or other have already been executed, our practical operations become doubly difficult, since we are constrained to endeavour to reconcile these with the improved details which correct principles induce us to prefer. By way of illustration, which will be found fully instructive, let us turn our attention to the works now in action upon and beneath the surface of our own metropolis, and consider how the principles here stated can be the best applied to improve the means of its drainage.

214. LONDON, standing upon a bed of clay, the substrata to which, successively, are plastic clay, chalk, and gault, occupies a part of the valley through which the river Thames has its course. The site of the town in some places rises gently from the river, and at others is below the level of high water, extending in dead flat districts.

For the principal part, however, the surface rises above the river, which therefore came to be regarded as the natural and proper channel for all the drainage of the town, the main sewers having been arranged to discharge their contents into it. Indeed, so thoroughly was this purpose of the river formerly recognised, that the Thames was familiarly termed the "*Grand Sewer of London.*"

215. Now, in order to make this method effective of only one of the true purposes of drainage, viz. the mere getting rid of the sewage matters,—it is evident that the arrangement must be such, that the whole of these matters are duly collected in the buildings and streets, and delivered into the sewers; also, that these are so constructed and situated that the matters they receive shall pass as rapidly as possible, and certainly without any interruption that would amount to stagnation, into the main sewers, and that these again faithfully and promptly convey the sewage into the final receiver, the river. So far, however, from being fulfilled in their entirety, no one of these conditions is fully and satisfactorily discharged. Thus, in many parts of the town, the refuse matters are collected in holes beneath the houses, and removed only when these holes become filled, and the surrounding soil permeated to supersaturation Some districts have no sewers or drains of any description; and again, of the sewers which are constructed, very—very few, are formed with a rate of declivity sufficient for the self-discharge of the sewage, while many of them are laid *perfectly level.* Attempts are made in some districts to obviate the evils of insufficient declivity, by a flushing of water through the sewers, the water being, for this purpose, accumulated for a time, and then suddenly released, so as to produce the effects of a powerful current. Of these methods some details will be found in a subsequent part of this treatise; but they can be regarded only as palliatives, and expensive ones, applying, moreover, to one only of the many imperfections of the present system. The crowning defect, however, exists at the last stage of this machinery,

where the outfalls of the sewers into the river are so low, that their contents are delivered at, or a little above, low-water level. The decomposing matters are consequently delivered upon the banks of the river, and left there to stagnate and poison the atmosphere, and to be brought up with the next tide for the thorough pollution of the waters. This is an irremediable evil of the present arrangement, by which no adequate fall can be obtained for the sewers, consistent with their discharge into the river near the high-water level, the only position in which the sewage could be effectually conveyed away from the higher towards the lower districts. Into some of these sewers the water of the tide is permitted to enter, the immediate consequence of which necessarily is, that the discharge of the sewage is suspended, and the gases engendered by the decomposing matter within the sewers are driven back towards the town. The return of the tide of course assists the outflowing of the contents of the sewers to some small extent; but, notwithstanding this expedient for assisting the discharge, the sewers are found to require periodical cleansing by hand, the foul matters being raised to the surface in buckets, and conveyed away in carts.

216. Of the many details of imperfection which mark the existing combination of arrangements constituting the sewerage of the metropolis, all who have studied the subject are, to some extent, cognizant, and all are equally prepared to admit the magnitude of the several improvements which have been made within the last twenty years, and which tend to alleviate some of the most palpable evils of the prevailing system; but no thorough rectification can be effected until the correct principles of town-drainage are recurred to, and applied with such modifications as may enable us to make the best use of existing arrangements, without sacrificing objects of greater magnitude and importance.

217. All the real difficulties of the drainage of London have their origin in the great error of attempting to convert

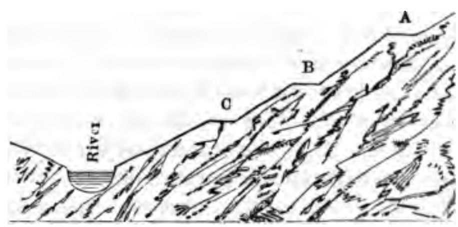
the river Thames into the common receiving sewer. In the attempt to accomplish this improper object, the sewage is brought down from the high lands, distances of miles, and heights of many feet, away from the very points where it should have been collected, and would be at once available for agricultural purposes. In the same attempt it has been found necessary to construct the lower ends of these sewers of immense size, in order to contain the accumulated sewage with which they are thus loaded. As the buildings have been extended, or a necessity has arisen for accommodating lower levels, the main sewers have been industriously removed, and rebuilt below their former position, and their capacity enlarged, to provide for the increased quantity poured into them. In the same obstinate attempt to pollute the waters of the river, miles of sewers have been constructed without any declivity whatever, on an absolute level, in which, as a necessary consequence, the refuse matters accumulate and solidify, until some happy rush of surface-waters sends them onward to the common receptacle, from which the population has the privilege of afterwards supplying their personal and household wants. Now, let us banish the notion of turning our rivers into sewers, and consider how the sewerage could be best arranged, supposing it had to be done as an entirely new work, and that we were unfettered by any consideration of making present subterranean structures available for the purpose.

218. Without seeking records of the actual levels of any one of our river-watered towns, we may assume as a feature common to many of them the existence of several ranges of elevation, running parallel, or nearly so, to the direction of the river, which we will suppose to be generally east and west. These ranges of elevation will be interrupted at intervals by ancient water-courses, and also by small ridges running north and south. These several features of the natural surface will determine the most economical courses for the general system of drainage. Thus the highest of the ranges (which we will call A) should have a course of

sewers for the especial service of the districts above it; the next range (B) should have another course of sewers to serve

Fig. 67.

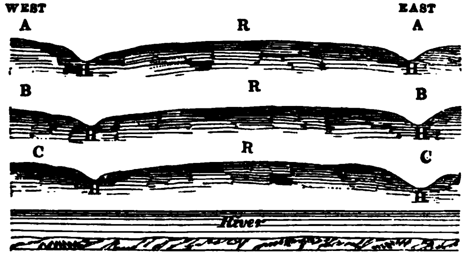
SOUTH NORTH



the district between A and B; the following range (C) should similarly be provided with its course of sewers to drain the district between B and C, and so on, as in the sketch, fig. 67. The general inclination, east and west, of each of these courses of sewers would be determined by the position of the ridges and hollows running north and south, as shown in fig. 68, where the highest points of the several

Fig. 68.

WEST EAST



courses would be at R, and the lowest at H successively. By this arrangement, means would be obtained of collecting the sewage at each level or range of elevation, and disposing of it with the minimum power to be expended in raising it for manuring purposes.

219. The next great question to be determined would

be, the most economical power that could be obtained at each of these points, H, for the purpose of raising the sewage for dispersion upon the land. For the lower level or range, the pumps could be worked by wheels driven by the tide of the river-water; and, in all probability, those for the upper levels could be worked, at any rate partially, by streams of water conducted, in suitable channels, from the uplands. At least, while we can command the immense water-power of rivers, and of the accumulated surface drainage from the large districts above, the best means of making this available for our purpose deserve all consideration, before we resort to the expensive power of steam. For the extended flat districts of towns which bound tidal rivers, the tides of the river could also be made available, to a great extent, in doing the work required. The completion of the scheme would then want the details of the arrangements to be made suitable to the superficial features and relative levels of each part of the site for the construction, &c., of the sewers, and the machinery to be applied for raising and distributing the sewage; and we should finally be prepared to arrange the minor channels or drains so as to subserve the efficient cleansing of every inch of the surface, and of every individual tenement in the town.

220. The arrangement here suggested will be the more peculiarly applicable, in proportion as the site resembles the general regularity of surface which we have supposed. In many parts of London there is no uniformity of inclination, and in others the rate of inclination is so trifling, that the surface may be treated nearly as a level. But the illustration we have referred to shows the general principle of the arrangement which would promote the greatest economy in the drainage of a town, the site of which resembles, in its principal features, the section given in fig. 67. In the application of this general system to London, *as it is*, these departures of superficial character from the theoretical regularity must of course receive due

attention; and, beyond this, the existing arrangement of sewers must be carefully noted and consulted, with the view of rendering them, as far as possible, available as parts of the general plan. Until this existing arrangement is presentable to the eye, upon plans and sections of the metropolis that shall exhibit every peculiarity of surface and of subterranean structure, by which the details of the plan to be adopted would be affected, no correct estimate can be formed of the extent of modifications that would be required, nor how weighty may be the reasons for relinquishing, in some parts of the town, the scheme of a succession of levels or ranges of elevation. An acquaintance with these details will probably show the expediency of making use of some of the existing main sewers through out the principal part of their length, but INTERCEPTING their contents before they reach the river, and forming tanks or other receptacles in which these matters should be collected.

221. The two objects—the public health, and economy—being kept distinctly in view in the design and execution of these arrangements, it becomes necessary to show that the sewage can be collected, treated, raised, and dispersed, without any detriment to the first of these objects; and that these purposes can be effected at such cost as will be at least balanced by the advantage of applying the sewage as manure, or a material for irrigation.

222. The contents of the sewers, consisting of human and animal excrements, earthy matters carried down by the surface water from the roads and streets, with some portion of decayed vegetable and animal substances, &c., although at first partly solid, afterwards become reduced to a thick liquid state, of tolerably uniform quality. During the putrefaction of these matters, the ammonia they contain (and which is one of their useful constituents) is disengaged; and if this process take place in the open air, it is of course mingled with the atmosphere in the form of carbonate of ammonia, and leaves the sewage in a less valuable condition. Now this volatile carbonate of ammonia may be

fixed in many ways. Thus says Liebig:—"Gypsum, chloride of calcium, sulphuric or muriatic acid, and superphosphate of lime, are substances of a very low price; and if they were added to urine until the latter lost its alkalinity, the ammonia would be converted into salts, which would have no further tendency to volatilize. When a basin, filled with concentrated muriatic acid, is placed in a common necessary, so that its surface is in free communication with the vapours issuing from below, it becomes filled, after a few days, with crystals of muriate of ammonia. The ammonia, the presence of which the organs of smell amply testify, combines with the muriatic acid, and loses entirely its volatility, and thick clouds or fumes of the salt, newly formed, hang over the basin. In stables the same may be seen. The ammonia escaping in this manner is not only lost, as far as our vegetation is concerned, but it works also a slow, though not less certain, destruction of the walls of the building. For, when in contact with the lime of the mortar, it is converted into nitric acid, which dissolves gradually the lime. The injury thus done to a building by the formation of soluble nitrates has received (in Germany) a special name—*salpeterfrass* (production of soluble nitrate of lime). The ammonia emitted from stables and necessaries is always in combination with carbonic acid. Carbonate of ammonia and sulphate of lime (gypsum) cannot be brought together at common temperatures, without mutual decomposition. The ammonia enters into combination with the sulphuric acid, and the carbonic acid with the lime, forming compounds destitute of volatility, and consequently of smell. Now, if we strew the floors of our stables, from time to time, with common gypsum, they will lose all their offensive smell, and none of the ammonia can be lost, but will be retained in a condition serviceable as manure. (Mohr.)" *

223. Chemistry thus supplies us with the means by which

* "Chemistry in its Application to Agriculture and Physiology," by Justus Liebig. Edited by Drs. Playfair and Gregory. Fourth Edition, *1847, p. 189.*

all the offensive and detrimental properties of the sewage may be suppressed, and all the useful properties safely retained. There is evidently no necessary reason why a tank or receptacle in which the sewage is collected and stored should be, in any respect, more disgusting to the senses, or injurious to the health of human beings, than a reservoir of the purest water.

224. Can the remaining question of *cost* be disposed of with equal satisfaction, so as to show that the application of the sewage to manuring purposes may be effected with due economy? Will the agricultural value of the sewage pay the expenses of applying it? We believe it may. These expenses will embrace the construction of the tanks or stores for the sewage, of the pumps and raising machinery, and the means of treating the sewage with gypsum or other agent, and of distributing it upon the lands to be served; but against the total, in a comparative estimate, would have to be placed the cost of the present partial removal of night-soil from cesspools, the immense additional cost incurred by the necessity of having immense sewers, the cost of outfalls into the river, and the expense of cleansing the present sewers by hand. Now, in order to form a rough estimate of these several expenses with which the present system is to be debited, we will assume the population of the metropolis to be two millions,* and the number of houses 200,000, that is, ten persons to each house on an average; that half of these houses are still drained into cesspools, and that the cleansing of each of these costs one pound annually. We shall then have 100,000*l.* as the annual cost of removing the contents of the cesspools of the metropolis. The number of miles of sewers constructed during the ten years from 1833 to 1843, throughout the metropolis, was about 120, or, annually, twelve miles on an average; and the excess of capacity in these sewers, made necessary by the deficiency of declivity, and the great length to which they are extended, probably involved a cost, in construction, equal at

* *See Appendix No. 5*, p. 194, for details applicable to later years.

least to 2000*l.* per mile. This item would thus amount to 24,000*l.* annually, in which the expense of outfalls to the river may be included. To these are to be added the expenses of cleansing the sewers by hand, which may be moderately computed at 10,000*l.* annually throughout the metropolis. We shall thus have an amount of 134,000*l.*, which would be annually saved in these items by the proposed system.

225. A very reduced estimate of the value, for manure, of the excreta of human beings (reduced avowedly for the sake of gaining public belief), represents it at 5*s.* for each person annually. The value of the produce of the population of London would thus be 500,000*l.* per annum. Admitting one-half of this to be now made available, we shall have the other half, amounting to 250,000*l.*, gained by the proposed mode of collection, and adding this to the 134,000*l.* estimated saving (224), we have a total of 384,000*l.* annually available for the expenses of construction and repair of apparatus, and current cost of collecting, raising, and treating the sewage of the metropolis. This sum will endow thirty-eight stations with an annual income each exceeding 10,000*l.* for interest of capital in first construction and current expenses of working and treating. And this number of stations appears fully adequate to realize all the economy of power which can be attained by judiciously providing for several levels in each district of the metropolis.

226. In order to show that this rough estimate as to the value of the sewage, and the cost of applying it, is not formed upon fallacious data, calculated to induce an unfounded preference for the method recommended, we may refer to the authority of the Superintending Inspectors under the General Board of Health, Messrs. Cresy and Ranger. Mr. Cresy, in reporting upon the present sanitary condition of the borough of New Windsor, and offering his official recommendations for its improvement, estimated the population at 10,200, and the annual value of the sewage manure at from 1000*l.* to 1500*l.* And for the first cost of

the apparatus for distributing this manure, he allowed an expenditure of 4000*l.*, being 3000*l.* for 10 miles of pipe, and 1000*l.* for pumping engine, &c. Mr. Ranger estimated the value of the sewage matters of the town of Uxbridge to be at least equal to 1700*l.* per annum, the population being 3219 (in 1841), or about 10*s.* for each person; and for the first cost of the distributing apparatus, he allowed 3500*l.* In reporting upon the town of Eton, of which the population was 3526, in 1841, Mr. Cresy estimated the value of the excreta at 500*l.* annually, and the cost of main sewers and tanks for the sewage at 1000*l.*

227. These estimates of the value of sewage vary from 2*s.* to 10*s.* 6*d.* per individual, between which our average of 5*s.* is certainly a safe medium. And the allowance for first cost of apparatus for pumping, &c., varies from about 6*s.* to 1*l.* 2*s.* per individual. If we assume 1*l.* as a safe average, the annual interest, at five per cent., upon two millions of pounds, being 100,000*l.*, we shall have 284,000*l.* left for the current expenses of our thirty-eight stations, or about 7470*l.* each annually, which must be admitted to be a very liberal estimate of the cost of pumping and treating the sewage.

228. Of the current expenses of distributing the liquid sewage upon the land, and of first conveying it from the stations to the districts to be supplied, whether by a system of piping, or by vessels, or carts, it will not be necessary to offer any estimate here. These duties will probably involve an expenditure which would have the appearance of being heavy, if not fairly compared with the cost now incurred in imperfect manuring on the one hand, and on the other, with the vastly-increased value given by the application of the liquid sewage to the products of arable and pasture lands. When the costs and the results of the two methods can be, from actual and extended experience, placed thus in juxtaposition, we are justified in anticipating that a large balance of advantage and economy will appear incontesta-

bly due to the system of applying and distributing the liquid sewage as here described.

229. The multiplicity of stations necessary to carry out the scheme of ranges of elevation may appear to involve practical difficulties, and objections of a serious character, that should be adverted to, and their real value shown in contrast to the advantages which this arrangement offers. The primary consideration which must be satisfactorily fulfilled is, the practicability of accomplishing this method without any sacrifice of health, by the raising and distribution of the sewage at and from the several stations. The treatment with gypsum, already alluded to, may, it is presumed, be carried on at such a cost as shall not impair the ultimate economy of the process, and in such a manner that no offence shall be committed against the most fastidious delicacy of sense. Indeed, the completion of the process would perhaps require that the gypsum should be administered either constantly, or at stated intervals, within the collateral or the main sewers, by which means all disengagement of foul gases would be prevented, and the sewage would arrive at the receiving tanks in an innocuous and fixed condition. But until this method is carried out, the tanks may be so covered in, and their contents excluded from association with the external air, as that the latter shall not suffer any contamination; and similarly the sewage, pumped up, may be distributed in closed pipes, or loaded into river or canal boats, or into wheeled vessels, so constructed of iron that the sewage, already purified in the tanks, shall be at once conveyed away, without exposure in the slightest degree. The great advantage, however, of effecting this purification at the earliest possible stage (and the only *perfect* system is that which shall provide for doing it in the drainage of each individual house) is too apparent to be disregarded or lightly estimated. It has been well remarked, that so long as our covered sewers are permitted to emit the noisome gases engendered by the putrefying

matters within them from the air grates and gully holes into the streets, they remain, to all intents and purposes, *nuisances*, and are nearly as dangerous and offensive as if they were open sewers. And when it is remembered that these very gases, which bring pestilence and death to our poor population, would, if retained within the sewage, constitute its most valuable properties, we surely find abundant reason for seeking the best practicable method of applying the purifying process before these dangerous properties are developed, and of transmitting the fructifying matters to our fields before their value has been thus grievously impaired.

230. Another objection which the system of ranges of elevation will probably meet with is, that the sewage matters cannot be made available at any great number of points within the town and its suburbs. This may be admitted. It is, indeed, very likely that no profitable use can be made of the sewage within some few miles of the metropolis; but it does not therefore follow that it can be more advantageously conveyed in sewers to the distant station, where it may, perhaps, be applied at once. If we had the materials for instituting a fair and exact comparison between the first cost of constructing and current expenses of maintaining, in a healthy condition, the deep and large sewers required for any system of sewage which is not mainly determined by the minor varieties of surface, and the expenses of transporting the sewage from many points by pipes or by river, railway or canal, with all the facilities we can now command for any general and extended system, the latter would be found to be recommended as strongly by its economy, as it undoubtedly is by its superior efficiency in subserving the health and well-being of the population. The economy of transmitting liquid matters in pipes is well known, and the cost has been estimated, by engineers, at $2\frac{1}{2}d.$ per ton for a distance of five miles, and to a height of 200 feet. This includes interest of capital and all current expenses. Railway tolls and canal dues

may indeed be regulated so as to afford but little facility for the transmission of manure at present; but wonderful modifications will be volunteered in these matters, so soon as the system becomes general, the demand for accommodation be increased, and the mechanical and chemical appliances for purifying and transporting the sewage rendered more ready and effective.

231. Any system of collection which attempts to concentrate the sewage at a few points must be attended with extravagance in one or more of three different ways. First, and constantly, in the enlarged capacity of sewers required, for two reasons, viz. the great quantity to be conveyed, and the extra size needed to compensate for the deficiency of declivity. Secondly, in the greater distance over which the sewage has to be transmitted. Or, thirdly, in the greater cost of raising it from the level of the sewers to the high surface above it. Thus arise objections to the propositions which have been made for conducting the whole of the sewage of London to one point, situated at a distance of several miles eastward of the town, in which case retransmission would become necessary, in order to supply districts in all other directions. And, on the other hand, if it be collected at any point towards the north or north-west, where probably the greatest demand for it would be found, the reservoir would be necessarily constructed at a depth from the surface which would entail immense and needless expense in raising the sewage for application on the land.

232. Another important point in which the many-station system offers advantages, which the single-station system does not, is the facility for storing the sewage for any required time, until it may be available for agricultural use It is well known that the manuring matters are required to be applied at certain seasons and intervals, according to the nature of the vegetation. If the sewage be collected in one reservoir, the size of it, in order to serve the true purpose of a reservoir or store-place, must be immense, almost to impracticability; but if divided, as proposed, between many

points, tanks of moderate size would be amply sufficient to contain the accumulation of long intervening periods, while the facility of distribution would, moreover, probably induce the use of the sewage for varieties of culture, that would tend to equalize the demand for it.

233. Sewers are, properly, *mere passages* for the sewage, but they are so only while the matters sent into them are induced to continue moving by the declivity of the sewer, or by the artificial force of water, or other agent, to drive or carry them forward. Without one or other of these aids the large sewers we have been constructing are known to become reservoirs of sewage, or cesspools, in which, during dry seasons, the refuse matters remain decomposing for days and weeks, sending up the most pernicious gases into the drains and water-closets of the houses, and through the air-grates and gully-holes into the streets of the town. The system which adopts ranges of elevation and varieties of surface, as indications by which to lay small sewers with rapid declivities, and leading into tanks situated at short distances from each other, obviates these evils, by constructing the sewers so that they maintain their proper character of mere passages, and the tanks are made to perform the double purpose of storing and purifying the sewage. The chamber of the tank into which the sewers discharge may be trapped, by turning down into water, so that no impure exhalations can possibly return along the sewer towards the houses and streets.

234. In adapting this arrangement to London, or any other town already provided with sewers, those in which sufficient fall exists may be retained and made to deliver into tanks at the lowest point of each range or district. But all sewers without fall, or with less than is sufficient for the rapid self-discharge of their contents, should be at once abandoned, and a separate system of sewers constructed, dipping into one or more tanks at the centre and other points of the flat district. As a general principle, to be very reluctantly departed from, the surface-water and

waste household-waters should be admitted as the only dilutants of the solid sewage. Artificial scouring or flushing of the sewers may be regarded as an expensive and troublesome correction of some of the evils occasioned by deficient declivity, but one sometimes attended with a most mischievous consequence, viz. the forcing up of the sewage into the streets from some of the lower sewers, which become surcharged with the flushing water during the process. Another expedient which is occasionally recommended, and in some cases practised, the scouring by admitting the tidal water of the river, is inapplicable to any method which purposes to preserve the sewage for agricultural uses; and must be admitted to have the effect of thoroughly defiling the lower banks of the river at which the discharge takes place.

235. Having thus shown that the true principle upon which towns should be classified in order to consider the best system of arranging their general drainage, is that of ranges of elevation and varieties of surface without any reference to contiguous rivers or water-courses, and having, in support of this principle, stated that the system of conducting the sewage to the river, besides wasting that which is really of great value and poisoning the water, necessitates immense mis-expenditure in large and deep sewers, it will be desirable, before closing this section, to cite some further authority as to the value of sewage manure, and notice the plans which have been proposed for applying that produced in London; and also to quote some few instances of the works which have been executed to provide for delivering the sewage of London into the river Thames.

236. The sewage of the city of Milan is collected in two concentric canals, the inner one of which is called the Sevese, and the outer the Naviglio, and delivered into one called the Vettabbia, which flows from the southern part of the city and, after a course of about ten miles, discharges into the river Lambro. Throughout its course this stream of sewage is made to flow over a large extent of meadow-land, and is found to possess such valuable fertilising properties that

the deposit, which has to be periodically removed in order to preserve the level of irrigation, is bought by the neighbouring agriculturists, and esteemed an excellent manure. Some of the meadows, which are thus irrigated by the sewage water of Milan, yield a net rent of 8*l.* per acre, besides paying taxes, &c. These meadows are mowed in January, March, April, and November for stable-feeding. They besides yield three crops of hay, viz. in June, July, and August; and in September they furnish ample pasture for the cattle till the irrigation in the winter.

237. The late Mr. Smith, of Deanston, in reporting to the "Commissioners for Inquiring into the State of Large Towns and Populous Districts," upon the "application of sewer-water to the purposes of agriculture," gave an interesting description of the method which has been adopted for upwards of 30 years in applying the sewage-water of part of Edinburgh to the irrigation of grass-land. "The sewer-water, coming from a section of the Old Town, is discharged into a natural channel or brook, at the base of the sloping site of the town, at sufficient height above a large tract of ground extending towards the sea, to admit of its being flowed by gravitation over a surface of several hundred acres. The water, as it comes from the sewers, is received into ponds, where it is allowed to settle and deposit the gross and less buoyant matter which is carried along by the water, whilst it flows on a steep descent. From these tanks or settling-ponds the sewer-water flows off at the surface, at the opposite end to its entrance. The water so flowing off still holds in suspension a large quantity of light flocculent matter, together with the more minute *débris* of the various matters falling into the sewers, and chiefly of vegetable and animal origin. The water is made to flow over plats or plateaus of ground, formed of even surface, so that the water shall flow as equally as possible over the whole, with various declinations, according to circumstances; and it is found, in practice, that the flow of water can easily be adjusted to suit the declination." "The practical result

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of this application of sewer-water is, that land. which let formerly at from 40*s*. to 6*l*. per Scotch acre, is now let annually at from 30*l*. to 40*l*., and that poor sandy land on the sea-shore, which might be worth 2*s*. 6*d*. per acre, lets at an annual rent of from 15*l*. to 20*l*. That which is nearest the city brings the higher rent chiefly because it is near, and more accessible to the points where the grass is consumed, but also, partly, from the better natural quality of the land. The average value of the land, irrespective of the sewer-water application, may be taken at 3*l*. per imperial acre, and the average rent of the irrigated land at 30*l*., making a difference of 27*l*., but 2*l*. may be deducted as the cost of management, leaving 25*l*. per acre of clear annual income due to the sewer-water." Mr. Smith calculated that 17,920 gallons of sewage-water, containing 5 cwt. of dissolved and suspended matter, are equal in fertilising power to 2½ cwt. of guano, or 15 tons of farm-yard manure; and he estimated the expense of the material and process, as applied to one acre of land, as follows:—

	£	s.	d.
Cost of manuring one acre of land with 17,920 gallons of sewer-water . .	0	12	9
2½ cwt. of guano at 8*s*. . . .	1	0	0
15 tons of farm-yard manure at 4*s*. . .	3	0	0

He further calculated that the comparative economy of the sewer-water manuring will increase with the greater quantity of each kind of manure applied; thus:—

Cost of manuring one acre of land with 35,840 gallons of sewer-water . .	0	16	6
5 cwt. of guano at 8*s*. . . .	2	0	0
30 tons of farm-yard manure at 4*s*. .	6	0	0

238. Mr. G. Stephen in his "Essay on Irrigated Meadows," published in 1826, had previously described the system of sewer-manuring with commendation. Mr. Stephen says, "Edinburgh has many advantages over many of her sister cities, and the large supply of excellent spring-water

is one of the greatest blessings to her inhabitants, both in respect to household purposes, and in keeping the streets clean; and, lastly, in irrigating the extensive meadows selected below the town by the rich stuff which it carries along in a state of semi-solution; where the art of man with the common shore-water has made sand-hillocks produce riches far superior to anything of the kind in the kingdom, or in any country. By this water about 150 acres of grass-land, laid into catch-work beds, is irrigated, whereof upwards of 100 belong to W. H. Miller, Esq., of Craigintinny, and the remainder to the Earls of Haddington and Moray, the heirs of the late Sir James Montgomery, and some small patches to other proprietors. The meadows belonging to the last-mentioned noblemen, and part of the Craigintinny meadows, or what are called the old meadows, containing about 50 acres, having been irrigated for nearly a century, they are by far the most valuable, on account of the long and continual accumulation of the rich sediment left by the water; indeed, the water is so very rich, that the proprietors of the meadows lying nearest the town have found it advisable to carry the common shore through deep ponds, where the water deposits part of the superfluous manure before it is carried over the ground. Although the formation is irregular, and the management very imperfect, the effect of the water is astonishing; they produce crops of grass not to be equalled, being cut from four to six times a year, and given green to milk cows. The grass is let every year by public auction, in small patches, from a quarter of an acre and upwards, which generally brings from 24*l.* to 30*l.* per acre. This year (1826) part of the Earl of Moray's meadow gave as high as 57*l.* per acre."

239. The results of experiments tried at Clitheroe, in Lancashire, showed that the fertilising properties of sewage-water were nearly four times as great as those of common farm-yard manure. Mr. Thompson applied 8 tons of the sewage-water to one acre, and 15 tons of the ordinary manure to another, and the produce of the former was as

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1·875 to 1 of the latter. Comparing the produce with the weight of manure, the proportion of the one to the other will therefore be as 1·875 to ·532, or nearly fourfold.

240. The sewage-water of Mansfield, in Nottinghamshire, has been so applied to lands by the Duke of Portland, that, with a preliminary expenditure of 30*l.* per acre, to put the land in a condition fit for irrigation, its annual value has been raised from 4*s.* 6*d.* to 14*l.* per acre. Mr. Dickinson treated some land at Willesden, in Middlesex, with liquid manure, derived from horses, and obtained fine crops of Italian rye grass, although the land had previously been deemed unworthy of cultivation. Mr. Dickinson obtained ten crops in twelve months. In the year 1846, the first crop (cut in January) yielded more than 4 tons per acre; the second gave nearly 8, and the fourth, cut in June, produced 12 tons per acre.

241. At Ashburton, where they have applied liquid manure for 50 years, and at other towns in Devonshire, the land thus treated produces grass at least a month earlier than lands not so treated, and is valued at 8*l.* to 12*l.* per acre, while land not so improved is considered worth only from 30*s.* to 40*s.*

242. One of the earliest, if not *the* earliest, of the suggestions for saving and applying the sewage of London appears to have emanated from the late Mr. John Martin, the artist, in the year 1828. Mr. Ainger, in 1830, published a plan for "preserving the purity of the water of the Thames," by constructing covered drains along the sides of the river to receive the minor drainage, and Mr. Martin in July, 1834, presented to the select committee of the House of Commons, then inquiring into the state of the law respecting sewers in and near the metropolis, with a view to suggest amendments, a "Plan for improving the air and water of the metropolis by preventing the sewage being conveyed into the Thames, thereby preserving not only the purity of the air, but the purity of the water; and likewise for manure and agricultural purposes" The objects of this

plan were described to be—"first, to materially improve the drainage of the metropolis; secondly, to prevent the sewage being thrown into the river, and to preserve in its pure state the water which the inhabitants are necessitated to use; thirdly, to prevent the pollution of the atmosphere by the exhalations from the river and the open mouths of the drains; and, fourthly, to save and apply to a useful purpose the valuable manure which is at present wasted by being conveyed into the river."

243. The details of the plan embraced the formation of a receptacle at Bayswater, on the north side of the Uxbridge Road, for the drainage of Kilburn, part of Paddington, Bayswater, &c., &c., and of another receptacle above Vauxhall Bridge to receive the contents of the present King's Scholars' Pond Sewer. For the body of the city, Mr. Martin proposed a grand sewer to commence at College Street, Westminster, and run parallel with the river, and to be extended to a convenient point near the Regent's Canal at the east end of London. And for the south side of the river, a similar plan was recommended, the sewer in this case to commence near Vauxhall Bridge, and pass along the bank of the river to Pickle-Herring Stairs, thence, branching off through Rotherhithe, to a convenient spot adjoining the Grand Surrey Canal, where a grand receptacle should be constructed similar to that by the Regent's Canal on the north side of the river.

244. These grand sewers were proposed to be constructed of iron, the bed of them being on the same level with the shore, and following the inclination of the river, about 7 in. per mile. The top of them to form quays, at least 2 ft. above the highest possible tide. To prevent the possibility of those sewers being burst by the accumulations of floods, they were to be provided with flood-gates; and to afford facility for inspecting, and, if necessary, cleansing them, light iron galleries were designed to be suspended from the roof. The sewers were to be built up of iron, the bottom paved with brick, and the top arched with sheet iron, with

wrought-iron ribs; the size of the sewers being on the average 20 ft. in depth and width, and the estimated cost of their construction 60,000*l.* per mile, including sewer, pier or quay, strong quay-wall of cast-iron, towards the river, &c., &c. The whole length of the two sewers proposed was about 7½ miles. The description of the receptacles in which the sewage was to be collected will be best quoted from the proposer's "Plan" submitted to the committee.

245. "The grand receptacle at the end of this great covered sewer should be 20 yards deep, and 100 yards square, with a division down the centre, separating it into two compartments, each 50 yards in width, with a flood-gate at the inner angle of each compartment for the sewage to run in at; and at the opposite extremity, within about 13 ft. of the top, there should be an iron grating, 5 ft. wide by 50 yards long, through which the lighter and thinner parts of the sewage would rise; the heavier and grosser parts would sink to the bottom, and gradually fill up the base of the drain, when the gate should be closed, and the one leading into the second division of the receptacle opened. At the extremity of the receptacle, between the two compartments, there should be an engine to raise the manure into barges, and also to pump the water in case of extraordinary tide; in this way the expense of an extra receptacle for the water accumulating whilst the tide is up would be saved; this, however, would only be required in spring tide. The receptacle would be so firmly built, and covered with a roof of wrought iron, supported by cast-iron pillars, that a road could be made over it; or it might be built upon, and thus no room would be lost; and, that a particle of smell might not be allowed to escape, there should be a communication for the foul air to pass from the receptacle to the fire of the engine, which would then completely consume it." It is of course unnecessary to remark that these estimates and particulars are quoted for their historical interest, and not for any practical value that attaches to them.

246. About the year 1845, a company was organised, we believe under the original auspices of Mr. Martin, and promoted by Mr. Smith of Deanston, which proposed to carry into effect, for the general benefit of the metropolis, a plan for collecting the sewage by means of a receiving sewer which should cut the existing sewers at a mean distance of 620 yards from the river. Mr. Martin, the founder of the Company, however, objected to this, preferring to receive the contents of the sewers near their outfall into the river. The Company referred to—the "Metropolitan Sewage Manure Company,"—contemplated the "conveying of the sewage-water of London, by means of a system of pumping engines and pipes, analogous to that of the great water companies, and thus distributing the fertilising fluid over the land in such manner and proportions as may be best adapted to the various kinds of field and garden cultivation." The proposals of the Company were eventually limited to an operation upon the sewage belonging to the King's Scholars' Pond Sewer, one of the principal sewers in Westminster, and with this reduced purpose an Act of Parliament was obtained for prosecuting the scheme in 1846.

247. The actual proceedings of the Company, their results and defects, were described officially in a Report (dated 25th December, 1851) to the General Board of Health, by one of their superintending inspectors, W. Lee, Esq., and from this Report we extract the following:—"I thought it my duty to visit the works of the Metropolitan Sewage Manure Company, at Fulham, to examine the market-gardens and other land to which the sewage *has been applied* there, and to ascertain from some of the consumers their opinions as to the result upon various crops. The Company has a station on the west bank of the Kensington canal, at Stanley-bridge, where they have erected a steam-engine to pump the sewage water over the top of a stand-pipe 75 feet high. This altitude gives a sufficient pressure for the whole district, and the fertilising fluid is conveyed from the stand-pipe and distributed, by about 15 miles of mains and services, varying from 14 inches diameter at the works

down to 2 inches diameter in the fields and gardens where it is used. The consumers have plugs or hydrants fixed at convenient distances in their lands, and with their own servants, and hose and jet pipe, apply it when they please, paying to the Company the sum of three pounds ten shillings per acre per annum.

"Hitherto the Company has only taken the Walham Green sewer-water, which contains, probably, less fertilising matter than any other in the metropolis, in consequence of the less density of the population within its area, and the great volume of the upland rain water. It is, however, the most conveniently accessible to the works. When the arrangements for using the Ranelagh sewer-water are completed, it is expected that more beneficial results will be experienced.

"The first place I examined was a field from which two crops of grass have been taken during the year, and it is now a most excellent pasture. I examined the large market-garden occupied by Mr. G. Bagley, who said, in answer to my inquiries:—

"'I have found that all crops grow faster and are healthier from the application of sewer-water. The size of vegetables is increased in a fine season; in some descriptions the quality is also better, and consequently they would obtain better prices. I may particularly mention vegetable marrow, a plant that requires much nutriment; it has produced a large crop in warm dry weather. In dry weather, the sewage is of great assistance to scarlet runners and French beans, but if rain were to come after its application, the consequence would be injurious. I have found it of great service to cucumbers, especially from the convenience of its application. I think, however, it is almost better for cabbage and brocoli, than anything else. I have not perceived any offensive effluvia at the time of its application or afterwards—not enough: if there had been a little smell, the manure would perhaps have been better than it was.'

"Mr. E. Bransgrove, manager of Mrs. Harwood's extensive market-gardens, said:—

"'We have used the sewer-water ever since the Company

commenced. The improvement in the plants is very manifest; I think it helps to lessen the blight. The growth of vegetable marrow is much improved, also of scarlet runners, and the same of lettuce and celery. This plot was celery, and the liquid manure was applied to it. After the crop was got off, it was planted with cabbage, without any further application of the sewage, but the plants are still benefited by the former application. The next patch of savoys had it applied to them about three months since, and are a very good crop. There was very little smell either at the time of its application or afterwards.'

'I likewise visited the market-gardens of Mr. W. Bagley, Mr. R. Steele, Mr. J. Crouch, and Mr. J. Bagley, to all of which, as well as many others in the district, the sewage manure has been applied. In one place, a field of cabbage plants was pointed out, and I was informed that the sewage manure had been applied to about one half and not to the other. Those to which it had been applied were darker in colour, larger, and much more vigorous than the remainder.

"I have, in my former report, already considered the objection urged in the provinces, *that liquid manures could only be beneficially applied in* WET WEATHER, and have shown that the solution used was too strong. It is a remarkable fact, that the tenants of the Metropolitan Sewage Manure Company all concur in the statement, that *the greatest advantages are produced by its application in* DRY WEATHER, when manuring and watering are combined in the same operation. These facts, and my own experience, lead to the conclusion that *the town sewerage water should be collected, and raised to the required altitude in as concentrated a condition as possible; but that it should be distributed and applied to the land, in such a state of dilution with water, as may be required by the season of the year, the state of the weather, and the quantity of moisture in the soil.* This may be easily accomplished, and almost without expense, by a pipe from the water-works, discharging into the downward arm of the sewage stand-

pipe, at the command of the person in charge of the station. By these means, the sewerage water may be applied with advantage at all times. In dry weather, and upon thirsty soils, a weak solution would be used; and in the winter season—in wet weather, on uncropped land—or with gross-feeding plants, as strong a solution as might be requisite, to produce the greatest possible fertility.

"Having said this much of the Company's operations, I feel bound to add that the failure of a sewer manure company in the metropolis, as a commercial speculation, was predicted by Mr. Smith, of Deanston and other competent agriculturists, who withdrew from it. A disproportionately large outlay of capital and machinery was made from a wrong sewer, that is to say, from a sewer which, in fact, was an old watercourse, and chiefly adapted to the removal of storm water; and the supply of manure from this was carried to a wrong district, or one of the least suitable districts, namely, to a district already supplied at the cheapest rate with powerful manure: of that district only a small proportion received the Company's supply. The whole of the available capital was expended before the pipes could reach the ordinary farming district, where there appeared to be a demand for it. Nevertheless, the fertilising power of the extremely-diluted manure, when applied to the land, already highly charged with manure, was extraordinary. On this land, where town manure had been applied at an expense of 20*l*. per acre, and labour in working the land to about the same extravagant amount, an augmentation of nearly one-third of the ordinary large crops was obtained. The range of the distribution by the jet was visible in the extra growth of the vegetation, although much of this success was no doubt attributable to the water itself, irrespective of the matter in solution."

248. Every sanitary reformer must have regretted that the Company has not been more successful; but when its operations are pointed to as a reason why works for the application of the sewage of towns should not be undertaken,

it becomes necessary to indicate the causes of its success being partial only. The errors committed are in matters of detail; the principle—that town sewage water is a valuable fertiliser—is fully confirmed, even by the Company's operations.

249. During the inquiries upon this subject which were instituted by the Sewage Company, some proposals were elicited which differed considerably from those upon which the Company is now acting. Two of these may be noticed, which were examined by the select committee, appointed in 1846, to consider plans for the application of the sewage of the metropolis to agricultural purposes. It should be mentioned, that the original plan of the Metropolitan Sewage Manure Company embraced the formation of reservoirs, in which the sewage was to be collected from the sewers, but these reservoirs were relinquished by the promoters of the bill, in consequence of the objection made against them by the owners and occupiers of land.

250. One of these proposals was to carry away the entire sewage of the metropolis, in a tunnel of from 8 ft. to 12 ft. in diameter, and at a depth of from 40 ft. to 80 ft. beneath the surface. This sewer was to commence at the Grosvenor Road, and pass through Westminster to the Strand, and on the south side of St. Paul's Churchyard, Cannon Street, &c., to the Commercial Road, thence under the River Lee, and in a straight line through the West Ham marshes, to a large reservoir and works, to be constructed in an angle between the western banks of Barking Creek and the northern banks of the Thames. The sewer-water was to be raised by steam-engines from the receiving reservoir into other reservoirs, sufficiently elevated to permit the solid matters being deposited at a level above the Trinity high-water mark. From these reservoirs the solid matter would be periodically removed, dried by artificial means, and then compressed and packed for transmission by land or water. The liquid matter was to be discharged as worthless, at all states of the tide. Mr. Wicksteed, the proposer,

calculated that engines would be required of an aggregate power equal to that of 1060 horses, and capable of raising, when worked at full power, 18,000,000 cubic feet to a height of 50 feet, in twenty-four hours, being considered equal to two and a half times the present ordinary quantity of sewer-water. The waste of the liquid sewage contemplated in this scheme destroys the purpose of what was intended to be a simple method of collecting the contents of the existing sewers.

251. The other proposal which received the attention of the select committee, and to which we will allude, was suggested by Mr. Higgs, the patentee of a method of treating sewage matters. Mr. Higgs's patent is dated 28th of April, 1846, and the object is entitled, "The means of collecting the contents of sewers and drains in cities, towns, and villages, and of treating chemically the same; and applying such contents, when so treated, to agricultural and other useful purposes." The scheme comprises the construction of tanks or reservoirs for the sewage, with suitable buildings over them in which the gases evolved are to be collected, condensed, and combined with chemical agents; and also an arrangement of spars or bars, on which the salts formed by this combination may crystallize. Apparatus is devised also for distributing the chemical agents over the mass of sewage, and the claims of the patentee extend to the use and application of them for the purpose of precipitating the solid animal and vegetable matters contained in the sewage, and of absorbing and combining with the gases evolved from it. "Hydrate of lime," or "slaked lime," and "chlorine gas," were the agents proposed to be employed for these purposes, and the solid matters were to be cut into suitable shapes, and dried ready for use. The committee, however, did not feel justified in recommending these elaborate processes, in the then immature state of the public mind upon the subject. *

252. Prior to the month of December, 1847, the sewers *of London were* controlled by seven separate boards of ma-

* *See further in* Appendix No. 6. pp. 225—228.

nagement or district Commissions, six of which belonged to London north of the Thames, and one to London south of the Thames. The six former districts were: 1, Westminster and part of Middlesex; 2, The Regent's Park, 3, Holborn and Finsbury; 4, The City of London; 5, The Tower Hamlets; and 6, Poplar Marsh or Blackwall. The one southern district included certain portions of the counties of Surrey and Kent. The several boundaries and extent of these districts are not worth definition, because they are now all (except the City division) included in one Metropolitan district, which is roughly stated to comprise a circular area of about twelve miles diameter, or about 114 square miles,* and to contain about 2000 miles of streets, and 1000 miles of sewers, consisting of old and new sewers, and open ditches.† The City Sewers District is about one square mile in extent, and comprises about 50 miles of sewers.‡ The progress of sewer-building in this City District may be imagined from the following facts, viz. that the commission began building sewers in 1756, and up to the year 1832 had completed 9 miles and 1035 yards. In the year 1843, Mr. Kelsey, their surveyor at that time, stated, above 35 miles of sewers were completed. The length of 50 miles now constructed is said to have completed the sewers as far as the *streets* of the district are concerned, leaving only *courts* and *alleys* to be provided for.

253. Let us briefly glance at the magnitude of some of the sewer-works which have been constructed, in the extravagant attempt to convey the entire sewage of London into the river Thames, and to maintain the subterranean channels in a clean and healthy condition. The Irongate sewer, which was formerly the city ditch, varies in height from 6 ft. 6 in. to 11 ft., and in width, from 3 ft. to 4 ft. The Moorfields sewer is 8 ft. 6 in. by 7 ft., and at the mouth,

* Evidence of R. Stephenson, Esq., before Select Committee on the Great London Drainage Bill, 13 June, 1853.

† Evidence of Mr. J. W. Bazalgette, before the same, 10 June, 1853.

‡ Evidence of Mr. W. Haywood, before the same, 13 June, 1853.

10 ft. by 8 ft.; and at the north end of the Pavement this sewer is 27 ft. below the surface. The Fleet Ditch, which drains the land from Highgate southward, is partly formed in two distinct sewers, which run on each side of Farringdon Street; they are from 12 ft. to 14 ft. high, and each is 6 ft. 6 in. wide, yet they are liable to be flooded by the immense rush of waters from the northward, and a single storm will raise the water 5 ft. in height in both of them almost instantaneously. The culvert constructed at the mouth of this sewer was severely injured, in 1842, by the flood consequent upon a thunderstorm. The Bishopsgate Street sewer, which receives the drainage of Shoreditch and adjacent places, is 5 ft. by 3 ft., is sometimes overcharged, and returns the waters from the high ground.

254. By way of conveying a ready idea of the vast size

Fig. 69.

of the Fleet sewer, the great length and extended functions of which have just been noticed, the two figures 69 and 70

Fig. 70.

are introduced, the one showing the section of the sewer at the city boundary, where its dimensions are 12 ft. 3 in. by 11 ft. 7½ in., and the other showing the size of the mouth of the sewer, which is 18 ft. 6 in. by 12 ft., and of ample *capacity to admit one of the largest* locomotive engines, the

gigantic dimensions of which are sufficiently familiar to all who have found it necessary to cross the platform of a railway station. Yet this sewer has often been surcharged; and only within the last year (1842) the culvert, so ably constructed at its mouth by Mr. James Walker, was severely injured by the flood consequent upon a thunderstorm.*

255. The large sewers constructed in the Tower Hamlets division are 4 ft. 6 in. by 3 ft., and the cost per foot varied from 15*s.* to 1*l.* 5*s.*, *according to the depth*. One of the sewers, from Hoxton New Town, is laid, for a length of 3000 ft., on a dead level, and discharges into another, which is also on nearly a dead level, because a fall could not be obtained. From the 45 miles of sewers in this division, about 2000 loads of sewage have to be annually removed by hand. All the outlets are into the Thames, below London Bridge, and are provided with valves, which sometimes fail, owing to some matter issuing from the sewers that prevents their closing, and of course the tide rushes in. Up to the year 1843, 13,000 ft. of sewers were rebuilt, at a lower level than formerly, in order to accommodate levels not then provided for, and at the same time maintain the communication with the river.

256. In the Surrey and Kent division, all the main arched sewers are necessarily provided with flaps and penstocks, nearly all the district being below the level of high water in the river. Some of the sewers in this division have only 2 ft. of fall per mile.

257. In the Holborn and Finsbury division, 38,000*l.* were expended upon the Fleet sewer between the years 1826 and 1843, and the surveyors were enabled to reduce the size of a part of it from 12 ft. by 12 ft. to 10 ft. by 9 ft., "from an advantage in the difference in the fall, there being more fall in this situation, which rendered the proportion of the current through the smaller sewer equal to the larger

* Evidence of the Surveyor to the City Commission of Sewers, before the "Commissioners of Inquiry into the state of large towns and populous *districts*." (1843.)

one." The extra expense incurred by the increased depth, which sometimes occasioned a passing through sand and treacherous materials, may be inferred from one item in the cost of construction, viz. that in such cases it was found necessary to use close timbering to strut the sides of the excavation; the sand also, sometimes, despite all precautions, rose 6 inches in one night; and the building of some of the sewers in Pentonville "had the effect of loosening the ground, or causing the ground to slip, the whole way up the hill," and thus seriously damaging the walls of the gardens above. The Fleet sewer, as already described, takes the water from Highgate and Hampstead, conducting it towards the river Thames, and it has been known "to rise six, eight, and ten feet in a night; there have been instances of persons being carried away by it." The fall in that part of it which is 12 ft. by 12 ft. is at the rate of a quarter of an inch in 12 feet; and in the 10 ft. by 9 ft., the fall is three-quarters of an inch in 10 feet. The effect of this difference of declivity is, that "if the 12 by 12 were completely full, the other would not be full by 2 ft."

258. The following details respecting the Fleet sewer are quoted from a report dated 25th October, 1853, made by Mr. Haywood, the Surveyor to the Commissioners of City Sewers. The Fleet sewer is the largest in the metropolis. An area of land six or seven times the size of the whole City of London is drained by it, the waters of that area being carried into it by many hundred collateral sewers. Near the outfall—that is, at the Crescent, Bridge Street, Blackfriars—the flow of these accumulated waters is probably from 18,000 to 20,000 gallons per minute during the day in dry weather; with but slight rain, the flow is so much increased that no man can stand against it; with a very moderate quantity of rain, falling uniformly over the drainage area, it is questionable if a horse could maintain its footing against the current in the sewer; with heavy rain the sewer is half filled. The difficulties attending repairs to the Fleet and similar sewers are very great. The

City Sewers Surveyor reported that a portion of the Fleet sewer, between Fleet Street and Blackfriars Bridge, being in such a condition as to require extensive and immediate repair, it was determined to put in a new invert, and underpin the side walls, and for this purpose to construct a dam across the sewer, so as to lay the bed of it dry. In order to avoid complaints of street interruption or other public nuisance, the works were commenced and carried on without opening any portion of the sewer itself, the only means of ingress and egress being one small hole 3 feet wide and 3 feet long in a branch sewer in Crescent Place. Down this small opening the workmen descended and conveyed all materials required, at great labour and time, and, necessarily, cost. Moreover, mechanical appliances, which are used with so much advantage in many similar works, and by the aid of which, with sufficient space, an amount of work five hundred times that done in the Fleet sewer could have been performed in the same space of time with ease, could not be used, owing to the insufficiency of space, and, therefore, manual labour, applied at immense disadvantage, was all that could be adopted. The men were frequently working with two thirds of their bodies immersed in water, amid an uncertain light, and a deafening roar of water, and at times, with but little chance of their lives, if they had once lost their footing. Half of the 24 hours the tidal water was in the sewer; when it was out, the men could with difficulty work three hours each morning, especially on Saturdays; and at other times, if any rain came down, the work had to be suspended at once. The sewer was never entirely free for 24 hours either from rain actually falling, or the drainage waters from the upland districts after the rain; and actual progress was made only in one tide out of every three or four. Two or three times, when dams were all but complete, heavy floods of rain washed the larger portion of them away.

259. The following extracts from the evidence given by Mr. Roe, surveyor to the late Holborn and Finsbury Com

mission of Sewers, before the Commissioners of Inquiry into the state of large towns and populous districts, in 1843, will give some notion of the state of the sewerage of that division. "The Holborn and Finsbury divisions are peculiarly situated, having no immediate communication with the river Thames. The waters from these divisions have to pass through one or other of the adjoining districts, namely, the city of London, the Tower Hamlets, or the city of Westminster, before reaching the river. The sewers of the Holborn and Finsbury divisions have, therefore, of necessity, been adapted to such outlets as the other districts respectively afforded; and these having formerly been put in without due regard to an extended drainage, the sewers of these divisions have not had the benefit of the best fall that could have been obtained. Of late years many of the outlets have been lowered in the adjoining districts; but to alter the existing sewers of these divisions to the amended levels would require the rebuilding of about 323,766 ft. of sewer, at an expense of nearly a quarter of a million sterling." In this state of things, Mr. Roe conceived that the ordinary current of water which passes along the covered sewers (in some constant, in others periodical), in these divisions, which, in numerous cases, does not prevent deposit from accumulating, might yet be made available for that purpose; and accordingly "a series of experiments were commenced, in order to ascertain what velocity could be obtained in the sewers; and it appeared that deposit might be removed by the means of dams placed in certain situations to collect heads of water, at less expense, than by the usual method. Another series of experiments were made for the purpose of endeavouring to ascertain the proportion of decomposed animal and vegetable matter, and detritus from the roads, carried through the sewers to the river Thames by the common run of water. Several square boxes were constructed, to hold 1 cubic foot of water each. These were filled with water from different sewers. After allowing the

turbid water to clear itself by precipitation, I ascertained the relative amount of the precipitate. The following were some of the results:—From the river Fleet sewer, near the outlet, the proportion of decomposed animal and vegetable matter, and detritus from streets and roads, held in mechanical suspension, was 1 in 96. The run of water was 10 in. in depth, and 10 ft. in width, having an average velocity of 83·47 ft. per minute, passing 692·8 cubic feet of water per minute; the matter conveyed being 7·21 cubic feet per minute, or 103·660 cubic yards per annum. The river Fleet sewer conveys the drainage of about 4444 acres of surface, or about four-sevenths of the surface of these divisions. That great quantities, in addition to the above, are carried away by the force of water in rainy weather is certain; allowing this source, and the remaining three-sevenths of the district to only equal the discharge by the river Fleet sewer, there appears to be a quantity of upwards of 200,000 cubic yards of matter carried to the Thames per annum from these divisions in mechanical suspension, and by the force of velocity, weight, and volume of water." In one part of this division (at Canonbury) the sewer is *sixty-eight feet below the surface*, and *the drainage of the houses is provided for by a subsidiary sewer.*

260. In the Westminster division the outfalls to the river vary from 10 ft. to 15 ft. below the level of high-water mark, that is about 5 ft. above low-water mark, and some of them are provided with flaps. The cost for cleansing sewers by hand, made necessary by deficient fall, amounted, in the year 1842, to 1850*l.*; the average for seven years, being about 1,550*l.*, and the deposit is so hard that it is sometimes found necessary to use the pick-axe to dislodge it. Some of the main sewers have a fall of only ½ inch in 100 feet. During the ten years ending 1843, 27,056 yards of sewers were constructed by the Commissioners for this division, and these were principally old sewers *built at a lower level*, or diverted along the public way. The size of the main sewers is 3 ft. in width, and 5 ft. 6 in. in height,

and of this size 32,000 yards were constructed from 1833 to 1843 jointly by the Commission and by individuals. In 1843 one of the sewers in this division, the King's Scholars' Pond Sewer, was described to have from its commencement at Shepherd's Well to the flood gates at the Thames, a total fall of 285 ft. 4 in., yet the fall is in some parts very deficient. In the Pimlico district adjoining the palace, the fall is for the last 5500 ft. only 5 ft.;—less than a foot in each thousand feet, and the outlet was still so low that flood gates were necessary at its outlet. During the rising of the tide, therefore, these gates were closed for six hours, and the sewage of course remained pent up or thrown back towards the houses.

261. In the Kent and Surrey divisions, in which there are several open sewers, the drainage is so conducted that "during the time the tide is up in the river, the sewers have to receive all the water, making its way into them, and must be sufficiently capacious to hold both that quantity, and all rain that may fall, until the fall of the tide allows a discharge." The covered main sewers are 5 ft. 3 in., by 4 ft. 9 in. The whole of the district is many feet under high-water mark.

262. The facts here quoted are certainly sufficient to show that the system of draining into the Thames is attended with vast extra expense in the depth and size of sewers, and with great inconvenience and inefficiency in the want of declivity thereby laboured under, which are powerful considerations against the propriety of this method, and the weight of which has to be added to that of the loss occasioned by the utter waste of most valuable manuring matters, and the injurious effects of saturating these matters in the water from which the daily supplies for the metropolis are mainly derived.

263. Having thus briefly noticed some of the details of the sewerage arrangements of the metropolis, as carried on under separate commissions prior to the year 1848, it is desirable to notice some of the proceedings of the United

or "Metropolitan Commission," since that time, including their proposals, estimates, and actual works. There is good reason for extending this notice, sufficiently, moreover, to embrace a general review of these proposals, since they present to us the labours of the highest engineering talent yet brought to bear upon the great question, How can London be properly drained? The new commission, appointed in December, 1847, consisted of the following members:—Lord Ebrington, Lord Ashley, Dr. Buckland, Mr. Hume, M.P., Hon. F. Byng, Dr. Arnott, Dr. Southwood Smith, Sir J. Clark, Rev. W. Stone, Professor Owen, Sir H. De La Beche, Messrs. R. A. Slaney, M.P., J. Bidwell, J. Bullar, W. J. Broderip, R. L. Jones, J. Leslie, and E. Chadwick. In the Session of Parliament 1848, an Act (11 & 12 Vict. c. 112), was passed, entitled, "*An Act to consolidate and continue in force for Two Years, and to the end of the then next Session of Parliament, the Metropolitan Commissions of Sewers.*" This Act of 1848 was amended by another (12 & 13 Vict. c. 93), passed August 1st, 1849, entitled, "*An Act to Amend the Metropolitan Sewers Act.*" By these Acts powers were given for making district rates, and levying contributions for building sewers, for making sewer rates partly prospectively and partly retrospectively, for levying and recovering "improvement rates," and borrowing money on mortgages and annuities "*to pay off any debt not actually due.*"

264. On July 23rd, 1849, at a Special Court of the Sewers' Commission, a report was read from the surveyor of the Metropolitan Commission at that time (Mr. Phillips), embracing plans and estimates he had prepared for the drainage of the metropolis. In this report, the principles of town-drainage were laid down as follows:—

"1. That two outfalls, independent of such other, should be provided, one for the discharge of natural, or land and surface waters, and the other for the discharge of artificial, or house and soil drainage

"2. That in order to perfectly drain the subsoil of the

town so as to free it from damp, and to carry off, as quickly as possible. the natural waters, a system of permeable land drains and sewers should be provided to discharge into the natural watercourses and rivers.

"3. That as outfalls are already provided by streams and rivers for the discharge of the natural waters, it is only necessary to provide separate and proper outfalls for the discharge of the artificial, or house and soil drainage, which outfalls should convey the sewage, as fast as it is produced, to a depôt at a convenient and unobjectionable place, quite clear of and below the town.

"4. That in order to carry off the house and soil drainage without contaminating the atmosphere of the town by the escape of effluvia through the numerous inlets, as is at present the case, a system of impermeable drains should be provided, distinct and separate from the permeable land drains and sewers, to discharge, without intermission, into the said artificial outfall independently of the river.

"5. That at the main outlet a depôt should be formed, and works established for raising the sewage, and for converting and distributing the same for agricultural and horticultural purposes."

265. For the discharge of artificial, or house and soil drainage, the surveyor proposed a tunnel extending from the Plumstead marshes to Twickenham, and crossing under the River Thames eleven times. The proposed course and construction were as follows:—From the depôt at Plumstead to pass under the river to East Ham and Plaistow marshes, recrossing the river from below Bow Creek to the Greenwich marshes, where a shaft would be provided, and a branch drain to serve Charlton, Greenwich, &c. Then to cross the river again to Blackwall, where another shaft and main branch drains for Poplar, &c., would be constructed. Continuing between the export and import West India Docks, the tunnel would reach the margin of the river, and a shaft and branch drain for Limehouse be provided.

Crossing to the Surrey side, the tunnel would run through Rotherhithe, and have two shafts and branch drains for Rotherhithe, Deptford, and Hatcham, westward, and following the bank of the river eastward.

The tunnel would leave Rotherhithe just below the entrance of the Grand Surrey Canal, and continue under the river to the Middlesex side between the entrance to Shadwell Dock and the Rotherhithe tunnel, and run south of the London Docks through Wapping to the margin of the river above the entrance of Hermitage Dock. Two shafts would be built along this part of the line, and connected with branch drains, one westward to the Tower and along Thames Street to Blackfriars, intercepting all the sewage running into the Thames as far as the Temple Gardens. From the east shaft a branch would be carried for Wapping. Leaving the entrance of Hermitage Dock, the tunnel would cross the river to the Surrey side near Shad Thames, and continue through Bermondsey, Southwark, and Lambeth, below Westminster Bridge. Four shafts and deep main branch drains would be constructed on this length, to serve the house drainage of Bermondsey, Southwark, Lambeth, Newington, Kennington, Walworth, Peckham, Camberwell, Dulwich, Norwood, Streatham, Stockwell, Clapham, Brixton, Battersea, Wandsworth, Tooting, Mitcham, Carshalton, Merton, &c.

From the Surrey side the tunnel would pass under the river below Westminster Bridge to Westminster, and continue through that district to the King's Scholars' Pond sewer at Pimlico; thence to Chelsea, and between Fulham and Hammersmith, crossing the river to Barnes, recrossing to Mortlake, and finally crossing above Richmond Bridge to take up the sewage of Twickenham and the neighbourhood. The line here described, although thus appearing circuitous, may be seen on a map to thread the windings of the river in a uniform curve.

266. The tunnel here proposed was to have a fall of

49 ft. 9 in. throughout its length ($19\frac{1}{2}$ miles), a diameter of 8 ft. at its outlet, and 6 ft. at the upper end. The following was the estimate for the work:—

Constructing $19\frac{1}{2}$ miles of tunnel sewer, at an average of £23,709 per mile, including shafts	£512,323
Constructing the shaft at the terminus	4,099
Steam engine, pumps, and boilers, complete	95,000
Engine house, &c.	33,577
Total estimated cost of $19\frac{1}{2}$ miles of tunnel sewer, with machinery, &c.	£644,999

The annual cost of maintenance, consumption of coals, and superintendence, was set down at 15,000*l.*, and it was calculated that the rated value of the property draining into this tunnel being 10,000,000*l.*, an annual rate of 1 penny in the pound for 22 years would suffice to pay the principal and interest. The depôt (at Plumstead marshes) would be 10 ft. deep, and elevated above the surface 20 ft.; an average of 10,000,000 cubic feet of sewage were expected to be discharged into it during the day, and this would be precipitated and filtered until the liquid parts were reduced as nearly as possible to pure water, while the solid matter remained. When there was no demand for liquid manure, it might be directed into the Thames or the sea, or otherwise disposed of as circumstances might render advisable. This gigantic conception appears to have served only for the Commissioners to talk about, and to elicit the geological objections of Sir H. De la Beche and Dr. Buckland, upon the ground that the tunnel could not pass through a continuous bed of clay, but must, for a great part of its length, be bored through beds of sand, gravel, and chalk, all of which are percolated by immense quantities of water, and would prove extremely unfavourable for such operations as those contemplated.

267 At the end of 1849 or beginning of 1850, the Commissioners appear to have become thoroughly puzzled by the conflicting advice of their own surveyors, and affrighted

at the task before them; and they desperately solicited anybody and everybody to tell them what they would recommend for the drainage of London. The invitation thus given for the sending in of "plans," was responded to by some 150 or 160 amateur drainers, of whom the only fact known is, that each of them became entitled, some time after they had tendered their recommendations, to receive a printed map from the Commissioners, showing what the sewer system of London at that time *was*, a kind of information which one might have supposed should have *preceded* their suggestions for its amendment.

268. In October, 1851, when a new Commission was formed, of which Mr. R. Stephenson and Sir W. Cubitt, the eminent engineers, were members, these 150 or 160 plans, which had lain till then unexamined, were exhumed, and carefully considered and reported on by a sub-committee appointed for that purpose. "Upon the report of that Committee," says Mr. Stephenson,* "Mr. Forster, the then engineer of the Commission, proceeded to design a plan for the general improvements of the sewage of London, and more especially with a view to the interception of it, to remove it from the Thames as far as possible in the vicinity of London. I was connected with Mr. Forster, at least I took a great interest in the question, and every step he took I was cognizant of. I examined the greater part of London, and more especially directed my attention to the lower districts on the south side of the Thames, which are so badly drained at present, and which are, in fact, the seats of diseases of all kinds. We proceeded so far as to complete our plans for the south side, and were about to let the contracts; but a question was raised as to the powers of borrowing money, and pledging the rates of the districts. It was found we had no such power; therefore we had no means of proceeding with our contracts. We had then an interview with Sir George Grey on the subject, with a view

* Evidence before Select Committee on the Great London Drainage Bill, *13 June, 1853.*

of bringing a Bill into Parliament, to authorise us to raise money for those purposes. Very shortly after that interview, the Government was changed. I do not know what steps were taken by the next Government, but I believe none, and I believe none are now being taken by the Government to relieve the Commissioners of Sewers from their embarrassments."

269. The plan designed by Mr. Forster, and here referred to, comprised two sewers, a high-level sewer, and a low-level sewer, the former to receive the natural drainage or rainfall and surface-water, and conduct it to a low part of the district, as Bow Creek, by gravitation simply; the low sewer to collect all the house drainage, and convey it also by gravitation to Bow Creek, where it would be pumped up and descend with the surface-water to the outlet at Barking Creek. By this plan, the districts that were proposed to be drained by *gravitation* comprised a very large proportion of the whole area of the north side of the Thames, admitting of a sewer falling 4 ft. a mile, commencing at the extreme west of London - Bayswater—and continuing to the River Lea, where Mr. Forster proposed that there should be reservoirs, if necessary, for the purification of the sewage; but that would be conveyed into the Thames conveniently at all times. With respect to the *low-level* tract, it was proposed (commencing, as in the high-level sewer, at the lifting point on the eastern bank of the River Lea) to construct a sewer at a depth of 47 feet below the invert of the high-level sewer, proceeding beneath the River Lea near to Four Mills Distillery, taking the north-western bank of the Limehouse Cut, at which point it receives a branch intended to intercept the sewage of the Isle of Dogs; thence continuing along the bank of Limehouse Cut, through a portion of the Commercial Road, Brook Street, and beneath the Sun Tavern Fields, into High Street, or Upper Shadwell, at a point opposite to the church; thence along Ratcliffe Highway, and Upper East Smithfield, across Tower Hill, through Little and Great Tower Street, Eastcheap,

Cannon Street, Little and Great St. Thomas Apostle, Trinity Lane, Old Fish Street, and Little Knight Rider Street; thence beneath houses in Wardrobe Terrace, and on the eastern side of St. Andrew's Hill, along Earl Street and Blackfriar's Bridge. From Blackfriar's Bridge it was proposed to construct the sewer along the river shore to the junction of the Victoria Street sewer at Percy Wharf, which sewer, between Percy Wharf and Shaftesbury Terrace, Pimlico, would thus become an integral portion of the intercepting line. The whole length of this main sewer, from the River Lea to Bayswater, was about 8 miles, the section of sewer 8 ft. by 5 ft. or 5 ft. 6 in., and the estimated cost 1,200,000*l.*

270. The want of powers to raise money, under which the Commission laboured, as already explained in quoting Mr. Stephenson's Evidence, necessitated the suspension of proceedings, and shortly afterwards (in 1851) the death of Mr. Forster deprived the Commission of their professional adviser, and opened the door for a careful reconsideration of the plans he had proposed. In October, 1851, Mr. R. Stephenson and Sir W. Cubitt accepted the appointments of Consulting Engineers to the Commission, and various minor works or those of "drainage," merely, as distinguished from the ulterior purpose of "intercepting" the passage of refuse matters into the Thames, were, during the following two years, sanctioned and executed.*

* The following record of estimates for works ordered by the Metropolitan Commission may be useful: –

Ordered 6th September, 1850.

				£	s.
340 ft. of	12 in. pipe sewer,	Shepherd's Bush	. . . . .	70	0
120 „	12 „	Kent Road	. . . . .	22	0
550 „	15 „	Hanway Street	Oxford Street .	320	0
175 „	12 „	John's Court			
220 „	12 „	Petty's Court			
133 „	9 „	Lisson Grove	. . . . .	25	0
50 „	9 „	Portman Market	. . . . .	20	0
40 „	6 „				
500 „	9 „	Portland Street, Walworth	. . .	50	0

271. From a statement of the affairs of the Metropolitan Sewers Commission, read at a General Court, on the 6th September, 1853, it appeared that when, previous to July, 1852, the power of the previous Commission to call for a rate of 6*d.* in the pound was reduced to 3*d.*, 200,000*l.* was the sum required for their ordinary annual expenditure; but that after this, they were empowered to raise not more than 100,000*l.*, although they had entered into contracts which could not be withdrawn; that when the New Commission was issued in July, 1852, after giving credit for all the rates, there was still a balance of 36,000*l.* against the Commissioners; that in the last 12 months, the present Commission had executed, at the public expense, brick and pipe sewers to the extent of 28½ miles in length, con-

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450 ft. of	2 ft. brick culvert,	in line of Falcon Brook	. .	120	0
360 ,,	12 in. pipe sewer,	Brick Street, Park Lane .	. .	90	0
350 ,,	12 ,,	Crown Court, Temple Bar	. .	87	10
145 ,,	15 ,,	Moor Street, Marylebone	. .	95	14
200 ,,	12 ,,				
75 ,,	12 ,,	Lamb Court, Clerkenwell	. .	19	10
626 ,,	12 ,,	Fulham Road . . .	. .	106	0
50 ,,	9 ,,	Ebury Square, Pimlico .	. .	10	0
800 ,,	18 ,,	Camberwell Grove . . .	. .	450	0
940 ,,	15 ,,				
1140 ,,	12 ,,				
420 ,,	9 ,,				

Ordered 21st July, 1852.

170 ft. of 12 in. pipe sewer, in Chester Mews, Pimlico. Gradient 1 in 60 . . . . 32 10

660 ft. brick sewer, 3 ft. 9 in. × 2 ft. 6 in., in New Street Mews. Gradients 1 in 43, and 1 in 200. Materials—stock bricks, Portland cement, and blue lias mortar 350 0

100 ft. 12 in. pipe sewer, in Woburn Mews, West. Gradient 1 in 100. (Contribution £2 per house) 18 0

260 ft. brick sewer, 4 ft. × 2 ft. 8 in., in Highgate Road. Gradient 1 in. 122. Materials—stock bricks, Portland cement, and blue lias mortar 225 0

120 ft. of half-brick barrel sewer, 2 ft. in diameter, in Wandsworth Road 30 0

(*See page* 72 *for prices in* 1854.)

tracted for or put in hand 12½ miles, making a total of 41 miles in length, at the cost of 142,853*l.*; but there were many other works considered as public, though constructed at the expense of proprietors abutting on public roads; there had been 11½ miles of these public sewers constructed in that period, at a cost of 36,413*l.*; these sewers were built at private expense, but afterwards became the property of the public, and were cleansed and repaired at the public expense, the original proprietor receiving a contribution towards the expenses from all parties who drained into them; that besides these works and those executed at the public expense, there was a large amount of pipe sewers that could hardly be separated from public works. The length of these pipe sewers was 70 miles, executed at a cost of 44,108*l.* The works superintended by the Commissioners cost 80,521*l.*, and the new sewers, executed by themselves, 142,853*l.*, making a total for works superintended during the year of 223,374*l.* The works of the Commissioners, however, did not end there. There had been repairs, and the cleansing of open and covered sewers, and on these three objects they had expended a sum of 36,880*l.*

272. The state of funds in the several districts under the jurisdiction of the Commissioners, on the 30th June, 1853, was reported as follows: — Credit, 35,754*l.*; debt, 29,407*l.* 12*s.* 7*d.*; available balance, after taking credit for outstanding rates, 81,418*l.* 14*s.* 9*d.*; current ordinary expenses per annum, 59,177*l.* 5*s.*; estimated amount of extraordinary works ordered, 66,429*l.* 10*s.* 10*d.* Total prospective expenses, 125,606*l.* 15*s.* 10*d.* Available balance for further extraordinary works:—Credit, 8,723*l.* 16*s.* 9*d.*; debt, 52,911*l.* 17*s.* 10*d.*; amount to be derived from new rates of 6*d.* in the pound, 216,370*l.* Of this latter item an amount of 140,000*l.* might be collected within the year. Amount unprovided for, to be met by new rates, 44,188*l.* 1*s.* 1*d.* This statement does not embrace the following liabilities: — Permanent loans, 99,492*l.* 13*s.* 1*d.*;

claim for Ordnance survey, 24,212*l.* 17*s.* 5*d*; total, 123,705*l.* 10*s.* 6*d.* Special contracts to the amount of 46,508*l.* have been entered into, and duly executed, during July and August, in respect of the most important of the w rks ordered, but not commenced, or only partly executed, up to 30th June, 1853. The following are the amounts produced by a 6*d.* rate on the larger districts:—Ranelagh, 24,000*l.*; western division of Westminster, 37,000*l.*; eastern ditto, 21,000*l.*; Holborn, 23,000*l.*; Finsbury, 24,000*l.*; Spitalfields, 17,500*l.*; Surrey and Kent, 39,000*l.*; Counter's Creek, 5,200*l.*; Greenwich, 4,000*l.*; Fulham and Hammersmith, 2,500*l.*; Ravensbourne, 2,000*l.*; Richmond, 1,000*l.*

273 In October, 1853, the surveyor and consulting engineers of the Commissioners appear to have completed their plans for the main drainage of the metropolis, north and south of the Thames, which, after being received and adopted in Committee, were adopted at a Special Court of the Commissioners, held October 20th, 1853.

The report by the surveyor (Mr. J. W. Bazalgette) was mainly as follows:—

North Side of the Thames.

"The 'Hackney Brook, or Northern High Level Inter cepting Sewer,' will divert the whole of the sewage and flood-waters of 14 square miles of the upper districts from the low districts, and from the river Thames, thereby reducing the size and cost of construction of the sewers in the low districts, and preventing the destruction of property by floods, as at present.

"For instance, the Fleet sewer is now overcharged by the amount of drainage falling into it; it is uncovered for a great part of its length, through a dense population; and in other places it has fallen in, and has been temporarily repaired; but the Commissioners have never been able to apply an effectual remedy to it, on account of its present defective route, and the enormous cost of rebuilding so

large a sewer in a more direct line through a crowded population; and, as it has always been intended ultimately to divert its contents from the Thames, such a work could only have been of a temporary character; whereas now, by the diversion of the upland drainage, these difficulties will all be removed, and it and many similar sewers reduced to economical and permanent works.

"The amount of drainage received by this upper line will govern the sizes of the lower lines of intercepting sewers; and, as Parliament has now sanctioned the construction of a tunnel railway along the New Road, which will intercept our present main line of sewers, and necessitate the immediate construction of an intercepting sewer along its route, this upper line is rendered the more immediately imperative.

"This upper sewer will be in itself a complete and perfect work, and independent of any other intercepting sewer; it will afford an advantageous means of flushing and cleansing the sewers in all the low districts above which it passes, and thus improve their drainage; and it will relieve the neighbourhoods of Stoke Newington, Kingsland, Clapton, and Hackney, from the nuisance of an offensive open sewer, known as the 'Hackney Brook,' and the latter places from frequent inundations.

"The route of this work commences with a sewer 4 ft. 6 in. in diameter, by a junction with the 4 ft. circular sewer now constructing as the outfall for the Hampstead drainage, in the line of the open Fleet sewer, its inclination being 1 in 72. It passes along Gordon-house Lane, crosses the Highgate Road at an inclination of 1 in 184, and intercepts the second branch of the Fleet sewer, being at this point 6 ft 9 in. in diameter. It then passes across the fields into the Tufnell Park Road, turns down the Holloway Road to its junction with the Tollington Road; at this point its size is increased to 10 ft. 6 in. in diameter, and it is laid at such a level as to enable it to receive a branch from the Edgware Road and Regent's Park, diverting the waters

of the upper portion of the Ranelagh and King's Scholars' Pond Sewers, and again intercepting the Fleet sewer at Kentish Town. From the Holloway Road it passes under the Great Northern Railway and New River Cut, taking nearly the same direction as the present open Hackney Brook sewer, for which it will act as a substitute, and falling at an inclination of 1 in 476 to the High Street, Stoke Newington, near to Abney Park Cemetery, where its size is increased to 11 ft. 6 in. in diameter. It then passes along the Rectory and Amherst roads to Church Street, Hackney; and from this point it is increased to 12 ft. 6 in. in diameter, and its inclination is 1 in 1320. Thence it crosses under the East and West India Dock Railway, along Albion Road, West-street, and through the Victoria Park, and under Sir George Duckett's canal, up to which point it is kept up to such a level that it may be carried over or under the River Lea Navigation; or the sewage may be diverted from the point at Sir George Duckett's canal down below the Lea Navigation, at Four Mills, retaining the present as a flood outlet; or the point selected would afford an advantageous position for the erection of sewage manure works. With all these alternatives held in view, it is proposed for the present to terminate this work with two parallel culverts, each 7 ft. 6 in. in height, by 8 ft. in width, discharging into the River Lea at the present Hackney Brook outfall. This sewer is kept at such a level (for the purpose of being carried over or under the River Lea, and discharging at high water by gravitation), that a portion of the drainage of the Hackney Marshes cannot be turned into it; this must either drain into the Lea, as proposed by Mr. Forster, or eventually be carried into the low level sewer, to be raised by pumping.

"It is further proposed to fix tide-gates at the mouth of the present Hackney Marsh open sewer, to prevent the ingress of the tide, and by this means, and the diversion of the upland sewage from it, to prevent the floods to which the Hackney Marshes are now subjected

"The estimated cost of the whole of this work, from Kilburn and Hampstead to the River Lea, and a branch to Four Mills, will be about 271,290*l*., and the probable cost of that part of it which it is now proposed to execute will be about 181,290*l*.

"The areas which would drain into this sewer amount to about 8913 acres, or 14 square miles."

Sir William Cubitt, one of the consulting engineers, having approved the plan, referred to the cost in the following words:—

"I have most carefully gone over the estimates, the prices of which are guided, in a great degree, by works of the same kind recently executed, and at this time in progress for the Commissioners, to which heavy percentages are added for contingencies and compensations, for which no exact estimate can be made. The total amount, as shown by the estimate, is 271,290*l*.; but, reasoning from analogy in similar cases, I strongly recommend that the probable total cost of this measure should not be stated, or, at least, I do not think myself safe in stating it at less than 300,000*l*."

South Side of the Thames

SURREY AND KENT DRAINAGE.

"In preparing a design for a high-level or catchwater sewer, which, in conjunction with a low-level sewer, will complete the main features of a design for the effectual drainage of the metropolitan districts on the south side of the Thames, and the diversion of the sewage to a lower point in that river, it has been sought, as far as practicable, to comply with the resolutions of the Commissioners in 1850, communicated to their engineer, the late Mr. Forster, on the subject of the main drainage; and, in describing the proposed scheme, it will be necessary, first, to call particular attention to the natural features of the district to be drained, which covers an area of about 24 square miles.

"The urban districts and more closely populated suburbs are bounded on the north by the river Thames, on the east by the river Ravensbourne, and on the west by the river Wandle; the southern boundary being a summit, or water-shed level, about Mitcham, Streatham, Norwood, and Sydenham. The river Thames now receives the drainage of this district from the Heathwall, the Effra, the Battle Bridge, the Great St. John's, the Duffield, the Earl, and several minor sewers along its course, for a length of 11 miles, between the outlets of the rivers Wandle and Ravensbourne. It is not proposed to intercept the rainfall upon the lands adjoining these two last-mentioned rivers; they will continue to receive it as heretofore. But it is proposed to divert from those lands, as far as practicable, the drainage of such roads and buildings as may be built upon them.

"The northern half of the entire area is mostly urban; and its general surface varies from the level of Trinity high water to 6 ft. below it. This tract has, doubtless, at one period, been a marsh covered by the waters of the Thames, although many of the houses upon it have now basements and cellars below the ground.

"The southern half is suburban, and its surface falls rapidly towards its northern or lower margin, from an elevation of 350 ft. higher; so that during heavy rains the floods from the whole of this upper district descend with great rapidity into the sewers of the two lower districts, and, the mouths of those sewers being closed by the waters in the Thames for about eight hours each tide, the sewers themselves, moreover, being insufficient to store the storm waters, the result is, that during that period the lower districts are flooded.

"It will be evident that it is impossible to maintain a continual and unintermitting flow in the sewers of the two lower districts. or to drain the cellars and subsoil, and make them dry and healthy, without the aid of pumping.

"The first object, therefore, has been so to intercept the

waters from the suburban, or high district, as to carry off the largest possible amount by gravitation, and, having thus relieved the low districts from periodical inundations. whereby their size is reduced to a manageable limit, to deal with them as hereinafter described.

"The high-level intercepting sewer commences at the north-west corner of Clapham Common, being of the ordinary form (3 ft. 9 in. by 2 ft. 6 in.), and falling at the rate of 1 in 341 to its junction with its northern branch, its route to this point being through Clapham, Park Road, Acre Lane, and Cold Harbour Lane, where it intercepts the Effra sewer near the Brixton Road, its size increasing in proportion to the amount of drainage to be received by it, up to 9 ft. 6 in. in diameter at the point where it receives the drainage from 2200 acres. From this point the main line falls at the rate of 1 in 1760, or 3 ft. per mile, to its outlet. And from the junction with the northern branch to the junction with the southern branch, it is 12 ft. in diameter, and drains 3500 acres, its direction being through Cold Harbour Lane, Love Walk, and fields to the Lyndhurst Road, where it receives the southern branch From this point to the outlet it is increased to two parallel culverts, each 11 ft. in diameter, passing mainly through fields and garden ground, and under the Brighton and North Kent Railways, near New Cross stations, to the mouth of the Ravensbourne, at Deptford Creek, into which it will discharge the drainage from 7850 acres by gravitation at high water of the highest tides.

"The northern branch commences with a sewer 4 ft. in diameter, by a junction with an existing sewer in Rectory Grove, Clapham; and it falls at an inclination of 1 in 175 through Larkhall Lane to Union Road. Here it increases to 6 ft. in diameter, and falls to its junction with the main line in Cold Harbour Lane, at the rate of 1 in 1472, again intercepting the Effra sewer at a lower point in the Brixton Road, and draining 650 acres through a 7 ft. sewer.

"The southern branch, or Effra diversion, commences

by a junction with the Effra sewer at Croxted Lane, near Dulwich. It falls, at inclinations of from 1 in 273 to 1 in 100, in a direct line to its junction with the main sewer in the Lyndhurst Road, being 9 ft. in diameter, and receiving the drainage from 3100 acres.

"These branches are important parts of the high-level sewer, and without them it will not answer. In particular, the southern branch will save the covering of an equal length (about two miles) of the present open Effra sewer, the waters of which, instead of descending by a circuitous route, and with a flat gradient into the lower districts, will be diverted at a high level to a point nearer the outfall; and thus the size and cost of the upper portion of the main line will be reduced to one-half of what would otherwise be required, while a deep outfall for a new district now subjected to floods, namely, Dulwich, will be provided.

"Taking the more comprehensive view of the drainage of the whole area, it is proposed to extend and slightly alter the design for the low-level sewer laid before the Committee on the 20th ult., so as to include the drainage of Battersea and Battersea Fields. The present scheme commences with a circular sewer, 5 ft. in diameter, at the level of the bed of the Falcon Brook, Battersea. It passes along Battersea Road, under the South-Western Railway, along Priory Road, Lansdowne Road, and the Clapham Road, to St. Mark's Church, Kennington Common, up to which point its inclination will be 1 in 1760, or 3 ft. per mile, and its size will then have been increased to 8 ft. in diameter. From this point it proceeds in the direction of Mr. Forster's line, by the side of the Surrey Canal, to the Old Kent Road, at an inclination of 1 in 2112, or 2 ft. 6 in. per mile, being at this point 9 ft. in diameter. It then proceeds along the Old Kent Road, in Coldblow Lane, where it leaves Mr. Forster's line, taking a direct course across the fields and market gardens, under the Brighton and the North Kent Railways, along New Douglas Street

and Griffin Street, to High Street, Deptford, its inclination for this length being 2 ft. per mile, or 1 in 2640, and its size 10 ft. in diameter. Up to this point it receives the drainage from 4450 acres. At High Street, Deptford, its size is increased to 12 ft. in diameter, being intended eventually to receive here an important branch sewer from the Lower Deptford Road, which will divert from the Thames the drainage of about 3300 acres. The main line then passes between the Gas Works and the Vitriol Works, near the Greenwich Railway, and under Deptford Creek, to a vacant piece of ground, well adapted for a pumping station, or for sewage manure works, or for continuing the line at some future time further eastward.

"The lift from the bottom of the sewer to Trinity high-water mark would here be 30 ft.; and from 1500 to 2000-horse power would have to be provided at the pumping station.

"The lengths of the proposed sewers would be as follows:—

	Miles.	Fur.	Miles.	Fur.
High-Level Sewer.				
Main line	6	2		
North branch	2	0		
South branch	2	1		
Total			10	3
Low-Level.				
Main line	7	4		
North branch	2	3		
Total			9	7
Grand Total			20	2

"The sections of these sewers are of a favourable character; their inverts generally average from 20 to 30 ft. below the surface; and a very small portion of the work will have to be tunnelled

"Careful attention has been paid to the character of the surface under which the sewers are to be constructed; pri-

vate property and houses have been avoided as much as possible; but, owing to the streets being irregularly laid out, it has not been practicable to effect this altogether, and in such cases the comparative value of the property has been duly considered.

"It will be observed that, to save the permanent cost of pumping, the gradients of the low-level sewer have been reduced; but the increase in the size of a sewer compensates for a loss of fall; and the sewers will still maintain, through their whole length, a velocity of current varying from 1½ to 2 miles per hour, with the ordinary flow of sewage, and during rains that velocity will be increased. In this sewer there will be a constant current of a large body of water, so that the average velocity will be sufficient to keep it clear from ordinary deposit; but there will also be a good opportunity of flushing it, together with the other sewers in this district, from the catchwater sewer and the Thames at high water.

"The *minimum* velocity of current in the high-level sewer will be about 2½ miles per hour, while at the upper end it will be considerably more.

"The drainage of those portions of the metropolis at present requiring a deeper outfall must not be made dependent upon any scheme of interception, unless such scheme is adequate to carry off the rainfall, as well as the sewage, from them. It therefore follows that, whatever scheme of interception is eventually adopted, if it be short of such capacity, the sewerage and drainage of the metropolis must be perfected and completed independently of it.

"If this reasoning be sound, it is manifestly more economical to construct one work which will answer every purpose, than to complicate it by the execution of duplicate sewers, in order to gain the same object which may be obtained by one; and it remains only to show that these sewers are sufficient to carry off the rainfall, as well as the sewage, from the districts for which they will be the outfall.

"An average of an annual rainfall amounting to 30 inches, added to the *maximum* daily flow of sewage, would give only 3000 cubic feet per minute upon the upper district, and 4000 cubic feet upon the lower district, while extraordinary thunderstorms, amounting to 1 or 2 inches in an hour, are recorded. These, however, generally occur during the hot seasons, when the ground absorbs and the air evaporates a large portion of the rain. Such storms are generally partial, covering but a small district at one time, and are never of long duration, so that the whole of the waters that have fallen upon the district do not reach the outfall sewer until after the storm has abated; and, a small portion only of the sewer being pre-occupied at the commencement of the storm, the remaining portion for some time stores the flood waters. A heavy and uniform rain of long duration is probably the most severe ordeal to which sewers are subjected, when, the ground and the air having become charged to their full extent, absorption and evaporation abstract but little from the sewers, and the feeder sewers, having also become charged, would be delivering to their full extent.

"The largest quantity of rain which fell in London in one day during the wet season of 1852 measured $1\frac{1}{3}$ inch; but storms, amounting to $2\frac{1}{2}$ inches in a day, although of rare occurrence, have been recorded, and these would deliver into the high-level sewer 45,000 cubic feet per minute, while it is capable of discharging upwards of 46,000. The low-level sewer will discharge 21,400 cubic feet per minute; and it is here proposed that the existing main sewers in the low districts should act as reservoirs during such extraordinary storms. From their construction, and the remarkable flatness of their level, they are peculiarly adapted to this object; and it is estimated that on these occasions they would store the surplus floods without the rising of the latter to an inconvenient height, and would again deliver their contents into the Thames at low water, or into the intercepting sewer, as it became free to receive them Thus the provision of engine power for such rare

occasions would be saved, and the existing sewers made available.

"The estimated cost of this work will be as follows:—

	£	£
High-Level Sewer.		
Main line . . .	195,600	
North branch . .	20,400	
South branch . . .	42,000	
		258,000
Low-Level Sewer.		
Main line . .	140,000	
North branch . . .	32,000	
Engines, pumps, &c.	100,000	
Land, buildings, &c., required for the permanent establishment . .	100,000	
		379,000
Total . . .		£637,000"

Extracts from the Report of the Consulting Engineers on the Surrey and Kent Drainage, or the Drainage of that portion of the Metropolis which lies South of the River Thames.

"The object of the measure is to drain, take off, or intercept all the rain-water and sewage which now fall into the Thames from the district which lies between the rivers Wandle and Ravensbourne, and does not at present fall into those rivers, the whole of which comprises an area of at least 24½ square miles, or 15,680 acres, of one-half of which the rainfall can be intercepted and taken off by gravitation; but the other, or lowest half, the greater part of which lies below high-water level, would have to be pumped up and delivered into the river at some point below London —say Deptford Creek—in the first instance, and subsequently at some point lower down the river, should such an extension be deemed advisable.

"It may be here observed that the pumping-station at

Deptford Creek would afford a most excellent situation for the manufacture of 'sewage manure,' by which means the sewage-water would be deodorised and delivered into the Thames, divested of its most offensive and deleterious matter, which by that process would (as is affirmed) be separated and converted into a most valuable product for agricultural purposes.

"To prevent mistakes and misapprehensions on the vast subject of draining this great metropolis, and particularly as regards its cost, we deem it proper to state in this place that the special object of this report is not the 'sewerage,' properly so called, of the metropolis south of the Thames, but, in reality, the construction of a work, by means of which the sewerage of the southern portion of London may be freed from flooding in the first place, and well drained in the next; in short, to produce the same effect that would be produced by raising the land on the south side of the metropolis 20 ft.; in which case, every main sewer could discharge itself into the river, either deodorised or not, as might be deemed advisable, without pumping, and the cost of sewerage would be the expense of the sewers only to effect the drainage of the basements of all the houses; and the whole expense of what is herein recommended is the construction of a set of underground main intercepting drains or 'arteries,' sufficiently low to do that by the artificial means of pumping which the Thames cannot do of itself by natural means; and it follows, of course, that the cost of putting things in this position, and constructing this 'arterial drainage,' is altogether over and above the usual cost and expenses of carrying into effect the sewerage of a town, a circumstance which cannot, in our judgment, be too strongly impressed upon the minds of those who are crying out (and certainly not without reason) for improved sewerage; for, supposing that the 'arterial drainage,' with its plant of steam-engines and pumps, costs, in the whole, three-quarters of a million sterling, it will probably cost another quarter to complete the 'sewerage'

of the district even as it now exists, leaving alone further extensions of the southern portions of the metropolis.

"Now, looking to the fact that no real benefit can be derived till the plan be fully carried out to the extent only as herein contemplated, and that the sooner it can be done the better, the question is, Can 750,000*l*. be raised forthwith to complete this 'arterial drainage,' and secured by special rates upon the whole district to which it equally applies, leaving the raising and expending of money for the common sewerage to be managed as at present in the different districts; the first would be a uniform and standing rate for a given long period, till the sum borrowed was paid off, with interest, which would be followed by a small uniform rate, to cover the current expenses of pumping, &c.; and the second, a rate varying both in district and amount, according to the wants and current expenditure of the district in which the new sewers or other works are situated.

"The raising of the funds necessary to carry any measure of this kind into effect, and securing the repayment, is of equal, or, perhaps, even greater importance, than the measure itself, and cannot, in our opinion, be too strongly impressed upon the Commissioners, and by them upon that department of the Government with which such matters rest; but we again repeat our opinion that the capital to be raised for the arterial drains, such as the Hackney Brook sewer, on which we have already reported, on the north of the metropolis, and the high and low level arterial drains on the south, should be considered as separate and distinct, both in the mode of raising and rating, and also of repaying the money, from that for the common sewers, which are made to discharge into the arterial drains.

"We have, &c.,

"W. CUBITT,

"R. STEPHENSON."

274. On the 27th of February, 1854, a Special Court of

Sewers, composed of members both of the city and metropolitan Commissions, was held, for the purpose of receiving, considering, and determining upon, the report of the surveyors to the commissioners, "upon the sewage interception and main drainage north of the Thames, a portion of the works described in such report having relation to sewers made or to be made within the City of London and liberties thereof." Appended to the report, which described minutely the localities through which the main sewers were proposed to be carried, was an estimate of the probable expense of the works requisite on the north side of the Thames, amounting to 1,378,190*l.* This is exclusive of the proposed "Hackney Brook" northern high-level intercepting sewer, estimated at 271,290*l.*, including the cost of the work from Kilburn and Hampstead to the river Lea, and a branch to Four Mills. Sir W. Cubitt, one of the consulting engineers of the Commission, added a revised estimate of his own as to the probable actual cost of the works described in the report, and also of those proposed for the south side of the Thames, including the extension to the Thames in Plumstead Marshes. As to the north of Thames intercepting system and conveyance down to Barking Creek, Sir William estimated 1,750,000*l.* instead of 1,378,190*l.* And for the south side he allowed 750,000*l.* for the works as terminating at Deptford Creek, and previously estimated by Mr. Stephenson and himself, besides 500,000*l.* for the extension of such works through Greenwich and Woolwich to an outlet in Plumstead Marshes, making a grand total of 3,000,000*l.* for completing the arterial and intercepting drainage of the entire districts north and south of the Thames.

275. It has appeared desirable to quote these reports at considerable length, in order to record the latest proposals emanating from the highest engineering authorities yet consulted on metropolitan drainage. The Commission, under whose authority these reports were prepared, however, on the occasion of the meeting last referred to, held on

February 27, 1854, adjourned *sine die*, in consequence of the receipt of a letter forwarded by order of Lord Palmerston, the Secretary of State for the Home Department, avowing his opinion that the system of drainage advocated by the Board of Health, (as distinguished from that adopted by the Commissioners) was "that which ought to be adopted, as combining the greatest degree of efficiency with the greatest degree of economy." Now, the essential difference between the "systems" advocated by the "Commission" on the one hand, and the "Board" on the other, will be apparent from the following extract from a letter addressed to Lord Palmerston by Mr. F. O. Ward, and referred to in his lordship's communication to the Commissioners just quoted:—

"The Commissioners of Sewers and the Board of Health are at issue as to the cheapest and best way of draining houses.

"The Board of Health advocate the drainage of each house block by tubular submain running behind the houses, and receiving the sewage of each by a short tubular branch. They recommend a large reduction of the sizes of drains hitherto employed; for the single house drain they recommend a 4-in. pipe; for the submain receiving several of these a 6, gradually expanding to 9, 12, and so on up to 20, as the lengths of the submain and the number of branches received by it increase; such drains, they say, are self-scouring, the run of water through them is so concentrated that it keeps them clear of deposit; the branches being very short, and running backward towards the drain behind, instead of forward beneath the houses towards a sewer in the street, have a quicker fall, and, in case of leakage, leak into the open air, not into the houses, while the cost is so much reduced by this method that blocks of labourers' houses may be thoroughly drained and fitted with sinks and soil-pans for an improvement rate of less than 2*d*. per house per week.

"The Commissioners of Sewers, on the contrary, recom-

mend large brick sewers under the street in front of the houses, beneath each of which they carry a long drain from back to front, strictly forbidding more than two houses being relieved by one pipe drain; a system which, whether otherwise good or not, certainly entails an enormous increase of expense on the house-owners, and thereby redoubles the resistance on their part to sanitary improvement.

"The Commissioners of Sewers lay great stress on the independence secured by their system to each house-owner, whose premises are traversed by his own drain only, which he may take care of or neglect as he pleases, as its stoppage can only injure himself. They allege against the Board of Health plan, that it trespasses on private property, that any stoppage of the tubular submain causes all the houses higher up to suffer, and renders it necessary for workmen to enter private back-yards to search out and remedy the evil. They also deny the self-scouring property of the tubular submains, and refer in support of their view to several hundred cases of stoppages in tubular drains collected in a report of Mr. Bazalgette.

"The Board of Health, on the other hand, declare the householders' pretended independence on this plan to be illusory, seeing that the big street sewer is, nine times in ten, an elongated cesspool, where the sewage of each stagnates to the detriment of all, while the stoppage of a branch drain running beneath a house on the old plan often causes stench in the houses on either side. Against the inconvenience of an occasional invasion of the back-yards by workmen, they set the greater inconvenience of periodical invasions of the street and stoppage of the traffic, besides tearing up of kitchen floors to get at foul drains under the houses In reply to Bazalgette's report, they bring forward examples by hundreds of pipe sewers working admirably year after year, and attribute such stoppages as have occurred to errors incidental to the first introduction of a *new system—errors* which, once known, may be avoided

Among these they cite the use, at first starting, of drain pipes which were too thin, so that they broke under the pressure of superincumbent earth, the uneven laying and careless jointing of pipes by the jobbing builders often employed (as in some parts of Croydon) on this work, the use of soil-pans with ducts as large as the pipe drains to which they led, and, above all, the often scanty and intermittent supply of water to the system. They further point out that a population accustomed to open privies and cesspools, available as receptacles for solid refuse of every kind (refuse properly due to the ashpit), have to go through a transitional period of a few weeks, while they are learning that such practice leads to stoppage of the new circulating system, and must be abolished along with the old stagnant cesspools. They say that many of the tubular sewers, put down as failures in Bazalgette's report, are at this moment working perfectly well, for which reason they take all his allegations with very great reserve. They point, with some reason, to Lambeth Square, New Cut, where the Commissioners have allowed 32 houses to be drained by four tubular back drains, which act perfectly well, quite as well as 32 separate drains could act, though these would have cost eight times as much; and they ask, why this eightfold cost should be imposed upon London at large by the very same authority which sanctioned in this square the combined drainage, which is found to work well."

276. On the 2nd March, 1854, on the motion for the second reading of the "Great London Drainage Bill" (which was negatived without a division), Lord Palmerston stated he was about to re-organise the Commission of Sewers, and that Commission had lately matured a plan for the drain age of the metropolis, which, upon full consideration, he believed to be a good one, and likely to effect the objects which the scheme now before the House was intended to effect. He thought there would be great advantage in the drainage of the metropolis being effected and managed by one central department in some degree connected with the

local authorities. Moreover, if it should be possible to realise that which, according to this Bill, might be realised —namely, the connection of the drainage of the metropolis with some commercial advantages from the transformation of sewage into manure—that also ought to be in the hands of Commissioners, in order that any such profit might be applied for the public benefit in diminution or relief of the rates raised for the construction of the sewers.*

SECTION II.

Supply of Water.—Public Filters and Reservoirs, &c.

277. *Quantity* and *quality*—criteria of every-day application—have special reference to the supply of water for every congregation or community of human beings. The varied practical purposes of domestic life to which this invaluable agent is alone applicable, and the intimate connection of many of these purposes with the health, life, and well-being of humanity, at once attest the high importance of abundance and of excellence in our command of water. Rivers, springs, and surface collections have already been enumerated as the several sources of water for the use of towns, and the advisability of resorting to one or other, or combinations of these sources, has been shown to have some dependence upon the superficial contour of the town and suburbs. Facility of supply, promoting the economy of the means, will of course always have great influence in determining the source to be referred to. Rivers and their feeders—brooks or streams—may be classed, as the most abundant sources in most instances, but their applicability can seldom be realised without some expenditure of power—natural or artificial. Surface collections and springs, on the other hand, are frequently applicable by the force of

* The subsequent proceedings of the various public bodies down to 1865, relating to the Main Drainage of the Metropolis, the Utilisation of Sewage, and the Purification of the Thames by Embankment, will be found noticed in the Appendix, Nos. 3, 4, and 6; pp. 194, 205, and 225.

gravity unaided by power, and requiring only suitable channels in which the supply may be conducted from the higher lands around the town. The cost of power has, however, lost much of its importance as an element in the calculation since the steam-engine has enabled us to perform constant and easily-regulated duty in the raising and conveyance of water at a very small expense; and, therefore, the comparative abundance of the several sources at all seasons will determine the preference rather than the susceptibility of self-propulsion.

278. Where a choice is afforded as to sufficiency of supply, however, the *qualities* of the water should be allowed great influence in ruling the selection. Tracing all these forms of immediate supply to the common original one of rain water, we may readily infer, from a knowledge of its ordinary properties, and of the effect of its subsequent treatment, the particular stage of this treatment at which it will be the most desirable to convert the water to our purposes. Rain water, as already shown (Part I. paragraph 54), contains ammonia, but it is, as well known, the least impure in constitution of any water at our command. All the earthy, animal, and vegetable matters with which water becomes charged, are extracted from the soil through which, or the surfaces over which, it passes. The nature of these matters depends upon the constituents of the soil which is percolated; the amount of them will be in proportion to the time during which the water is maintained in communication with the soil, modified of course by the degree in which they may be adapted for mutual action. Hence it follows that the scale of comparative purity would stand thus:—1. Rain-water. 2. Water from surface drainage. 3. Water from soil drainage or percolation. 4. Water from rivers or brooks. 5. Water from springs and subterranean sources. Regarding No. 4, however, it is to be remarked that the collection of the water in any kind of channel allows of a partial deposition of the heavier particles which the water has imbibed, facilitated, of

course, by the depth of the body of water, and the slowness of the current, or minimum of motion. And besides this, the exposure of water to the action of the atmosphere appears to assist the evolution of some constituents which impair its purity. Water from streams and rivers comes thus to be considered as next in comparative purity to rain water immediately derived, while that taken from springs and sources in which it has long remained in intimate contact with soluble earths and other matters, is found to have acquired a corresponding proportion of these impurities.

279. The different kinds of impurities contained in water have been explained (56 and 57), and the means of testing and correcting some of those shown (58 and 59). The process of filtration through the soil, which the water derived from subterranean sources undergoes, tends to separate the animal and vegetable impurities, and thus spring-water and well-water being comparatively clear, are commonly reckoned as pure. The matters which these waters nevertheless contain are, however, separable only by chemical treatment, while the impurities of river-water may be got rid of to a great extent by mere subsidence and self-filtering.

280. The several purposes for which water is required in a town, or collection of people, are—1. Ordinary domestic uses, including drinking, washing of persons, clothes, utensils, houses, yards, and watering gardens, &c. 2. Manufactures. 3. Supply of public buildings, baths, wash-houses, &c. 4. Extinction of fires. 5. Cleansing and watering of streets and thoroughfares. 6. Supply of fountains, and public gardens and pleasure grounds. 7. Miscellaneous and occasional purposes not included in the foregoing.

281. The supply necessary for the total of these purposes may be reduced into an average quantity for each individual of the population, and each square acre, yard, or *foot* of the superficial area of the town. The latter datum

will also afford the means of estimating the proportion of the supply which will be immediately rendered in the form of rain, and the difference between the amount of which, and the total quantity required, will represent the proportion to be served by other means.

282. Adopting 24 inches as the average annual fall of rain, and half of this as remaining after evaporation, as this quantity will facilitate an approximate calculation, and be sufficiently near the truth for the purpose, (an exact average for places, years, and seasons being scarcely calculable even by the most laborious computation,) it appears that 1 cubic foot of rain-water is annually retained upon each square foot of surface, or 9 cubic feet on each square yard, equal to 43,560 cubic feet upon each square acre.

283. For the first, second, third, and fourth of the purposes enumerated (280), a daily supply of 20 gallons for each individual will be a fair average, being more than sufficient in towns having an ordinary proportion of manufacturing operations carried on within them, and nearly, if not quite so, even in towns where an excessive proportion of manufactories exist. This may be inferred from the quantities now supplied in towns. In Preston, Lancashire, the supply by the Waterworks Company is on an average 80 gallons daily to each house, including factories and public establishments, and as the service is constant and the quantity unrestricted, it is presumable that much of this quantity is wasted, and, if properly reserved, might be made to supply, partially at least, the cleansing of the streets. The tenements occupied by the labouring classes in this town are estimated to consume only 45 gallons each daily. Assuming 5 as the average number of occupants of each house, the supply to each in these cases will be 16 and 9 gallons respectively. In Ashton-under-Lyne the daily supply to each house is 55 gallons, or 10 gallons to each person; and 18 factories in this town consume 1,103,000 gallons daily. Experiments tried in the year 1847 proved that the daily consumption per head of the

tenants supplied by the Ashton Waterworks Company averaged 6·245 gallons; while the quantity supplied to the mills in the neighbourhood averaged about 7 gallons per head in addition, making a total of about 14 gallons per head per diem. In Nottingham, the "Trent Water Company" supply 17 or 18 gallons per individual, daily, including the trade consumption. The quantities supplied by four of the leading companies in the metropolis are as follows:—(for 1850).

East London	100 gallons	per house	per diem.	
New River	114 ,,	,,	,,	
West Middlesex	150 ,,	,,	,,	
Chelsea	154 ,,	,,	,,	

These rates of supply will be found to corroborate the average we have assumed for each individual. Thus in the district supplied by the East London Water Company, including Spitalfields, Bethnal Green, Poplar, Limehouse, and other populous neighbourhoods filled with the poorer class of persons, it will be found the average number of persons is much above 5; 7 or 8 would probably be much nearer the truth. The New River Company also supplies populous districts. Many of their customers are similar to those just described, and the average of all would certainly give more than 5 persons to each house. In the districts supplied by the West Middlesex and Chelsea Companies, the population is mainly of another class, or rather classes, but all of which occupy larger houses than those in the Eastern and Northern parishes, and the average consumption in each house is high in comparison with the others, owing to two causes, the larger number of residents in each house, including domestics, &c., and the larger quantity consumed in baths and other means of private luxury and comfort which are beyond the command of the other classes of society.

284. Although it would thus appear that an allowance of 20 gallons per diem for each head of the population will

suffice for domestic and manufacturing purposes,* including the supply of public buildings and for the extinction of fires, we would prefer to provide for a constant service of 30 gallons, in order to make an ample provision for all possible casualties and increased demands. Water is pre-eminently so valuable, and, when properly sought, so cheap an agent, that extravagance should always be permitted rather than a deficiency be risked.

285. For the three remaining purposes, viz.:—the cleansing and watering of streets and thoroughfares, the supply of fountains, and public gardens and pleasure grounds, and such miscellaneous and occasional purposes as are not included in the six preceding classes, the average quantity of water required may be reduced, for an approximate estimate, into a given depth per diem, or annually, according to the surface occupied by the town and suburbs to be supplied. Towards this quantity, the rain may, as we have seen (282), be estimated to contribute an annual average depth of 12 in. available water. Now, allowing $\frac{1}{10}$th of an inch of depth of water to be daily required over the entire surface of the town for the several purposes stated, (and we believe this to be a liberal allowance,) we shall have an annual total depth of $365 \div 10 = 36{\cdot}5$ in., which may be regarded as 36 in., from which deducting the 12 in. supplied by the fall of rain, we have the remainder equal to 24 in. depth to be supplied by other means.

286. We thus derive a rule as to the quantity of water required to be supplied in any town, which calculates the total quantity upon two given data, viz.:—First, the amount of the population; and, secondly, the superficial extent of the town and neighbourhood to be provided for. Thus, by way of example, let us suppose a town having a population

* In June, 1850, it was estimated, upon official data, that there were 288,000 houses in the metropolis, of which 270,000 were supplied with water, the quantity of which was 45,000,000 gallons daily, or 167 gallons per house. For later years, see Appendix No. 3, p. 194.

of 100,000 persons, and an area of 1000 acres. The quantity required to be provided annually for this town, would be,

	Gallons.
Population $100{,}000 \times 30 \times 365 =$	1,095,000,000
Area $1000 \times 43{,}560 \times 2 \times 6 =$	522,720,000
Total annual quantity	1,617,720,000

allowing each cubic foot to equal 6 imperial gallons, which is sufficiently near the truth for a general calculation.

287. Having thus endeavoured to arrive at an approximate estimate of the *quantity* of water required for any town, formed upon the data of the amount of population and extent of surface to be supplied, we have now to refer to the question of *quality*, and cite such observations as we can, which have tended to exhibit the qualities of water derived from the several sources of rivers, springs, and surface collections, or superficial drainage. In these particulars it will also be useful to include such accounts of the topographical and geological features of the towns and districts referred to as we can collect from the trustworthy testimony of witnesses before public Commissioners.

288. The borough of Preston comprises an area of 1960 acres, a population (in 1841) of 50,131, and 9994 houses at the same date. The town stands principally upon a dry sand of the "recent formation," marl, clay, and gravel existing in some parts. At a depth of about 90 ft. from this surface-soil, the "new red sandstone" is found; the same rock forming the bed of the river Ribble, which through two miles of its course flows at about a quarter of a mile distance from the town, which has a general westerly slope towards the river, the highest sites being about 130 ft., and the lowest about 35 ft. above its low-water level. More than half of the town is supplied with water by the Preston Waterworks Company, which derives its supply from the "mill-stone grit" formation at Longridge, distant about seven miles eastward from Preston The remainder of the town

is supplied from wells. The whole of the supply from both sources is described as of excellent quality, but we have no analysis to determine its ingredients. The geological influences by which water derived from such strata as are here described is affected, are certainly likely to furnish a water of good general quality and comparatively free from soluble mineral impurities, while the elevated position of the town in relation to the river would discourage a resort to it for general supply upon economical grounds.

289. Chorlton-upon-Medlock, one of the townships of the borough of Manchester, from which it is indeed separated only by the little river Medlock, comprises an area of about 700 acres. The number of houses in 1841 was 6021, and the population about 29,000. The soil is of two kinds, stiff clay over the southern part of the town, and gravel chiefly over the northern. The geological formation is the new red sandstone, which is found at depths varying from 3 to 90 ft. from the surface. A stream called "Corn Brook" which flows through the township for more than a mile, and delivers into the river Irwell at a distance of about two miles, is little better than an open drain, and keeps that part of the town near to its banks in a damp and unhealthy condition. The supply of water is derived partly by a Waterworks Company from Gorton Brook, which affords the only stream-water fit for use, and partly by pumps from wells in the gravel and sandstone. The water from these latter sources is described as being "bright and sparkling and well tasted, but hard"

290. The town of Ashton-under-Lyne is built on a gentle declivity on the north-west bank of the river Tame, above which it is elevated from 30 to 40 ft., the surrounding country being remarkable for its generally level character. The principal geological feature of the neighbourhood is the great coal deposit, the surface-soil being clay and loam, and the subsoil clay and gravel. The sub-strata are chiefly schistus and sandstone, with intermediate layers of coal. The water for the supply of the town is derived

by a Waterworks Company from springs in the higher parts of the parish, and is of a medium quality, being such, however, that it is said to be "wonderfully" improved by filtration.

291. York, situated in the centre of an extended vale, lies between the rivers Ouse and Foss, and immediately above their junction. Both of these are navigable and tidal rivers, but the tide is prevented from rising to the city by a lock placed five miles below it. The available water is derived from the river Ouse, from wells varying in depth from 12 to 40 ft., and from borings from 350 to 380 feet deep from the surface. The inquiries of the Rev. W. Vernon Harcourt, and of Messrs. Spence and White, of York, have furnished us with much valuable and accurate information as to the qualities of these waters, and the geological conditions in which they are presented; and, from the records of these inquiries, a few facts may be advantageously quoted as illustrations of general principles which will be found commonly applicable to the several sources of water for the supply of towns.

292. From these records it appears that the total of *gases* contained in one gallon of river-water, from the Ouse, amounted to 10·4 cubic in., and the average of 14 waters from the springs, or superficial wells, amounted to 23·5 cubic in. That the total of solid contents (consisting of carbonates of lime, magnesia, and iron, sulphates of lime and magnesia, muriates of soda and potash, silica, and vegetable matter,) in one gallon of river-water amounted to 9 grains,—while the average of solid contents of the fourteen well-waters amounted to 64·96 grains per gallon, comprising the same carbonates, sulphates, and muriates as found in the river-water, with the addition of muriate of lime in some specimens, and of the nitrates of lime, soda, or magnesia in all. An analysis of the water from the deep springs, made by the Rev W. V. Harcourt, showed the presence of 96 grains of solid contents in one gallon, and of this quantity about half consisted of medicinal salts

viz., 33·9 grains of the crystals of sulphate of magnesia, and 14·4 grains of the crystals of sulphate of soda, besides a small proportion of bicarbonate of iron.

293. The causes of these differences of ingredients (which, together with considerable difference of level at which the waters are maintained in the several wells, evince their independence of each other, and of the river) are referable to the geological conditions under which they are collected. The section of an Artesian well sunk to a depth of 378 ft. in the city showed the following arrangement of strata:—clay and gravel, 18 ft.; fine river-sand, 60 ft.; sandstone rock and loose sand, 60 ft.; a thin seam of blue clay and water, and sandstone rock, 62 ft.; another thin seam of clay and water, and sandstone rock, 178 ft. The Rev. W. V. Harcourt describes this sandstone formation, and the structure of the bed of the river Ouse, as follows:— "This sandstone rock belongs to the beds of the new *red sandstone* formation, which crop out in a low line of undulating hills along the western margin of the basin of the vale of York, passing in a south-easterly direction from Rainton to Borough Bridge, and Ouseburn to Green Hammerton, and emerging again from beneath the diluvial covering of that basin at Bilbrough, within a few miles of York. The immediate substratum of the soil in this line over a considerable tract of country consists of these porous beds, and the water which falls or flows down upon it passes through them, between the seams of clay which alternate with the sandstone, along the dip of the strata, eastward to York; it is thus carried between the diluvium below the bed of the Ouse, and is dammed up under the superincumbent mass, in the reservoirs of the sandy beds, to the above-mentioned height of 15 or 20 ft. above the summer level of the river, to which height it is found to rise where the superior seams of clay are perforated by boring. The water of the Ouse consists chiefly of the contributions of the rivers which flow from the high hills on the north-west of York, (especially the Swale, the Ure, and

the Nid,) and are fed by the rains falling on their summits. The streams from this source, after percolating the *mill-stone grit*, with which those hills are capped, find their channels on the surface of the impervious beds of the subjacent *limestone* and *shale* along the valleys, and are conveyed on linings of *diluvial clay* across the edge of the superior strata, and over the drift-covered plan of the *red sandstone* to York. To this account of the geological conditions under which York is supplied with water, is to be added:—1st. That the gritstone hills which furnish the river-water include few materials of saline impregnation. 2nd. That the beds of the red sandstone in which the deep springs run are pre-eminently saliferous. 3rd. That the rubbish of centuries accumulated in some parts of the city to the depth of three or four yards over the diluvial beds, which contain the superficial wells, is full of decomposing matters, tending to mineralize and contaminate the water. The waters of these wells, accordingly, are highly charged with solid matters, amounting, on an average, to about 60 grains held in solution in an imperial gallon. In two cases Mr. Spence found in them from 6 to 7 grains of Epsom salts, and in one 11 grains; in two others he found 31 and 38 grains of neutral salts of soda and potash. In these last an infiltration may be suspected from the deep springs; but in general there are sufficient materials in and upon the drifted beds to account for the sulphate and carbonate of lime, of which the solid contents of these waters are chiefly compounded, and which render them harder than is desirable, either for drinking or for culinary use."

294. The evidence here so well adduced is amply sufficient to account for the differences observed in the chemical qualities and adulterations of the water derived from the several sources; while that from the river Ouse, on the other hand, furnished by the gritstone hills, being purer at its source, and subsequently improved by exposure to the air, contains only 9 grains of solid contents in the gallon,

and presents an exhaustless source of water of excellent qualities for all the purposes of the city.

295. The materials of some soils are particularly prejudicial in their effects upon water passing through them Thus peat impregnates the water passing through it to so great an extent, that it becomes discoloured, and thus exposes the origin of its impurity. Mr. Homersham, who devoted much attention professionally to the several water-sources around Manchester, has recorded his observations on this subject, and cites the confirmatory remarks of persons residing in the valley of Longdendale in that locality, that "upon heavy rains following a drought in the summer time, the water flowing down the streams is about the colour of London porter, and so strongly impregnated with moss and peat, 'that it can at such time be smelled a field off.'"* When the water derived from peat lands passes through mineral rocks of particular formation, a process of natural filtration is effected by which the colouring matter is absorbed, and the water emerges in a tolerably pure state. This fact was observed by Mr. Thom in examining water which flowed over or through a particular species of lava or trap-rock (amalgoiloid) in the hills above Greenock, and was found to have thus become purified equal to fine spring-water. Mr. Thom made good use of this observation by substituting this rock, obtained in that neighbourhood at a nominal price, for charcoal in the subsequent process of artificial filtering.

296. The town of Nottingham, which is chiefly at a considerable elevation above the surrounding country, on the southern, eastern, and western sides, occupies the declivity of the southern termination of a long range of hills, and has the valley of the Trent about one mile in width at its foot. Three-fourths of the town has an elevation from 50 to 200 ft. above the valley, and stands immediately on the new red sandstone rock, which, being absorbent, remains

* "Report on the Water that can be Supplied to the Inhabitants of Manchester and Salford, p. 85." Weale, 1848.

dry on the surface. The remaining portion of the town has a sub-stratum of similar material, but stands immediately on an alluvial deposit of gravel silt, and decayed vegetable matter, lying in the valley of the Trent or its tributary streams. By two of these, the Leen on the south, and the Beck on the east, which flows into the Leen, the waters are conveyed into the Trent. The town is supplied mainly by two water companies, whereof one derives its supply from springs, situated about 1½ mile north of the town; and the other from the river Trent, on the banks of which a reservoir and other works have been constructed. A small part of the population is supplied by minor works, which, by means of steam-engines, raise their supply from wells sunk in the new red sandstone rock. The quality of all these waters is described as being good, but those from the sandstone contain "carbonate of magnesia in notable quantity," besides the sulphate and carbonate of lime, muriate of soda, &c. It is quite certain, therefore, that this water is, for all ordinary purposes, impaired in its purity and value.

297. Liverpool is situated partly on the side of the ridge of hills forming part of Everton, Edge-hill, &c., and partly on the crest of a minor elevation, the valley between the two having been the original streamlet or channel, which discharged into the old pool. The sub-stratum of about two-fifths of the city of Liverpool is clay. Along the banks of the intermediate valley the soil is chiefly a deposit of mud, with occasional beds of gravel, and in some parts irregular masses of rock. Between this valley and the southern and eastern boundaries of the town, a mixture of yellow sand and rock is found in small thin beds, but generally resting upon solid rock at an average depth of 15 ft. Liverpool is supplied with water by two public companies, one of which derives its supply from springs at Bootle, distant 3 miles from the town, and the other from wells in various parts of the town. These waters were analysed by Dr. Trail in 1825, and found to contain "muriate of soda

and of lime, the last in very small quantity; sulphate of soda, and possibly a minute quantity of sulphate of lime, carbonate of soda."

298. The town of Bilston has a declivity towards the brook called Bilston Brook, at its base, the fall being steep in the upper part of the town, and gentle in the lower part. "The geological character of the country is that of the coal measures overlying the Wenlock limestone. The only peculiarity is the presence of porphyritic greenstone, and occasionally compact basalt. The soil of Bilston, where collieries have not been opened, has a preponderance of aluminous earth. The subsoil is generally brick earth. The sandstone is rather an important feature in the geology of Bilston, on account of its compactness and great thickness." The water for the town is chiefly supplied by a Waterworks Company, and, being collected by land-streams which flow over beds of limestone, becomes impregnated with lime, and thus acquires a considerable amount of hardness.

299. Newcastle-under-Lyne stands partly on the old red sandstone formation, and partly on a strong mine of clay which extends into the coal formation of the Pottery district. The water springing from the former formation is somewhat hard, containing a small portion of carbonate of lime. That from the clay is much more hard, from its greater quantity of this carbonate.

300. Bath, which is built partly on the slope and lower part of a hill, rising from the right bank of the river Avon, where it forms a considerable bend round from east and west to north and south, stands upon the nearly horizontal beds of clays, limestones, sands, and sandstones, which constitute a portion of the series of rocks to which the term oolitic has been given—from the oolite or oviform grains in many of the limestones. From the interstratification of these different kinds of rocks, conditions for the occurrence of springs are numerous, and they are accordingly often met with, and from these the town is supplied

with water for domestic purposes. These springs occur at various elevations above the height of the river Avon, from 120 to 160 ft. The qualities of the water raised from the several wells vary according to the beds of limestones, clays, marls, sands, &c., in which they are formed. In the alluvial ground, on the right bank of the river and lower parts of the town, trees are sometimes met with in great abundance. These lie beneath an alluvial red loam, about 8 ft. thick, resting on gravel of about the same thickness, and this upon lias clay. The water where these trees are found is abundant, but never good. Some of the wells in the lias furnish tolerable water, but there are examples of sinkings in it to a depth of 200 ft., from which no water has been obtained. The sections of many wells sunk in the neighbourhood of Bath show that the water is retained among the various beds of clays at great depths beneath the Great and Inferior Oolites, and produces springs by cropping out on the sides of the hills

301. While the topographical and geological character of the site of the town, and of the soil and sub-strata on which it stands, are the admitted guides as to the source or sources from which the town may be supplied with an adequate quantity of water of average goodness of quality, the criterion of quality as measured by relative *hardness* must be allowed a prevailing consideration. River waters, rendered impure chiefly by organic, animal, and vegetable matters, are susceptible of improvement by methods of filtration; whereas waters derived directly from drainage or internal springs are comparatively pure in these respects but, on the other hand, are charged in various degrees with earthy and mineral matters, which at once render them less fitted for domestic purposes, and far less readily susceptible of purification. The economical results of the qualities of the water supplied to towns have been adverted to at some length in the first Part of the Rudimentary Treatise on Drainage. (Paragraphs 57, 58, and 59.)

302. In concluding these remarks on the qualities of

waters from various sources as subjects for consideration in estimating their comparative value, we may usefully refer to the confirmatory evidence supplied by analyses made under the direction of the Superintending Inspectors to the General Board of Health, of the waters available in the several towns of Chatham, Uxbridge, Croydon, and Dartford, reported upon by Mr. Ranger. The analyses were made by Dr. Lyon Playfair.

303. The water now used in Chatham is obtained principally from surface drainage from the upper chalk, but it varies greatly in the degrees of hardness. Adopting, as is presumed, the same measure of hardness as that used by Dr. Clark, and explained in Part I. (58), the hardness of the surface water from nine places of collection varied from 17° to 56°, the average of the nine being 27°, while the water of the River Medway has only 5½° of hardness. This water, however, contains a large quantity of a yellow deposit; and, comparing the qualities of all the waters, the Inspector recommended that the supply should be taken from the Boxley Abbey Spring, of which the hardness stands at 17°. This spring is about 5 miles from the town, and the situation being backed by elevated ground and considerably higher than any part to be supplied, is peculiarly adapted for the construction of reservoirs and filtering beds if required. The Report leads us to suppose that the reasons for preferring to bring water a distance of five miles, while that from the river is accessible to all parts of the town, is to avoid the expense of artificial raising of the latter. The relative hardness is, however, an item of great moment, and should receive full consideration. The deposit remarked in the river-water occurs, there is no doubt, from earthy matters held partly in solution, which would be readily removable by filtering.

304. Uxbridge is now supplied with water from four public pumps, from wells, and by dipping from the branch of the river Colne. The hardness of the water from three town pumps and two others varied from 26° to 52°, the

average being nearly 36°. The hardness of the water from one of the Artesian wells was found to be 34°; of that from two others $14\frac{1}{2}°$ and 16° respectively. From the small degree of hardness in these two latter waters, we might conjecture some communication between these wells and the river Colne, the water of which has $15\frac{3}{4}°$, but the Report does not remark on this circumstance The Inspector advised that the adequate supply for the town should be derived from the river Colne, at a part which would be favourable for the construction of reservoirs, filtering beds, and other necessary works.

305. The waters now supplied to the town of Croydon from springs and wells are found to have an average hardness of $25\frac{1}{4}°$. That from the river Wandle has 16°·1, and Dr. Clark reports than an expenditure of 1 lb. of burnt lime will, by his "lime-water softening process," suffice to purify 800 gallons of this water, reduce its hardness to 3°·9, and effect a saving of curd soap required to form a lather with 100 gallons of the water, of $24\frac{1}{4}$ oz. The Inspector recommended the river Wandle as the most eligible source, from its contiguity to the town, the favourable quality of its water, and its sufficiency to afford the means for a supply upon the constant system.

306. The town of Dartford is now supplied by wells and pumps, and dipping from the river Darent. The water from seven of these sources, excluding the river, has an average hardness of nearly 18°, while that from the river has only $13\frac{1}{2}°$, and was recommended by the Inspector as being the most desirable for the supply of the town.

307. The third consideration affecting the supply of water for towns is the relative expense at which this supply can be obtained. Springs and other sources of the less pure waters, are, doubtless, usually of more ready and economical adaptation than rivers. Upland streams and water-courses are generally applicable to some extent for supplying the adjacent parts of the town and suburbs, but the higher elevations frequently involve extra cost in forcing

water from these lower sources. With a great scarcity of records of the cost of works and conducting of the existing arrangements for supplying water to towns, we are driven to form estimates which can only be assumed as approximate, but will nevertheless suffice probably to indicate the relative economy of the several methods of supply which may be adopted.

308. The main items of cost of the supply of water to towns are:—1, collecting; 2, storing; 3, filtering; and, 4, conveying. If the supply be derived from surface-drainage or springs at superior level, so that no raising is required, the first of these items will comprise the construction of open channels, aqueducts, or artificial rivers with tributary or catch-water drains where necessary If the supply be derived from a river or other source at lower level, this item for collection must be understood to include the expense of raising the water and delivering it to the storing or filtering beds, with such constructions of channels or piping as may be necessary for that purpose. The storing places or impounding reservoirs for drainage waters are sometimes so constructed as to answer also the purpose of filtration, and thus combine in one cost the items Nos. 2 and 3.

309. Mr. Robert Thom, who has successfully supplied several towns with water collected from surface-drainage and natural collections or basins, considers it desirable that the reservoirs should be large enough to hold at least four months' supply of water, this being necessary to provide against the irregularities of supply of water obtained from these and similar sources. For the storing of water taken directly from rivers and other ample sources from which an abundant quantity can at all times be commanded, reservoirs of less capacity are sufficient, and the first cost of construction is therefore reduced. The catch-water drains, in which the water is first received, are made to communicate either directly with the main reservoirs, or by the medium of aqueducts From the main reservoir the water

is conveyed by another channel or aqueduct into other reservoirs or regulating basins near to the town, and each of them so situated in elevation that the water from them shall rise above the highest desired service, and of such capacity that each will contain enough for two entire days' supply of water for the town.

310. If the water cannot be delivered into the regulating basins at sufficient elevation, artificial power will of course be required to raise it from the natural to the desired height. From the regulating basins it is delivered into two or more self-cleansing filters (as before described, Part I. paragraph 72), and from these into two distributing basins, whence the water is carried through the streets by a system of piping. Thus the town appliances are provided in duplicate, and the object of this is to enable one set of apparatus to be constantly commanded, and each to be alternately cleansed or repaired when necessary.

311. In our fifth Section of this Division we shall have to enter into the details of apparatus for conveying and distributing water. Our present purpose is to enumerate the general varieties of arrangements required according to the source from which the supply is derived.

312. The increased expense incurred in the formation of large reservoirs to hold a supply for a long period, such as four months, is certainly great, but not so when compared with the first cost of machinery and current expenses of raising water from rivers and sources of low elevation. The upper sources of springs and drainage-waters are, moreover, applicable in some cases where the others are inaccessible, or rendered so practically by the great distance and low elevation from which river-water can alone be conveyed and raised. The cost of constructing reservoirs may be estimated at about three-pence per cube yard on an average, if no extraordinary difficulties or expensive works are required. With reference to reservoirs as proportioned in capacity to the number of houses or persons supplied, the following particulars may be usefully

cited, referring to the operations in seven of the large towns in Lancashire, and reported upon by Dr. Lyon Playfair:—

Towns.	Number of Houses in Town in 1841.	Number of Houses or Tenants Supplied.	Capacity of Reservoir in Gallons.	Height of Surface of Water in Reservoirs above	
				Highest Parts of Town.	Lowest Parts of Town.
				Feet.	Feet.
Manchester . } Salford . . . }	57,238	30,000	{ 2,000,000	0	155
			{ 249,360,000	0	122
Preston . . .	9,984	5,026	50,000,000	36	160
Bury . . .	5,260	2,980	4,181,760	50	130
Ashton . . .	4,700	4,000	100,000,000	200	260
Rochdale . .	8,266	2,800	22,781,253	6	96
Oldham . .	8,220	5,620	85,000,000	30	300

The capacity and expense of reservoirs for drainage or surface-collected water will of course be regulated with a view not only to the wants of the population, on the one hand, but also with reference to the extent of surface to be drained, and probable quantity which will thus accumulate. From some statements given in the Report by Mr. Homersham, before quoted from, we may present the following figures:—

Names and Situation of Reservoirs.	Contents of Reservoirs.	Area of Drainage Ground.	Per Acre of Area.
	Cubic feet.	Acres.	Cubic feet.
Turton and Entwistle Reservoir, 14 miles N.W. of Manchester . . .	100,000,000	2036	49,110
Belmont Reservoir, 14 miles N.W. of Manchester	78,000,000	1796	43,430
Bolton Waterworks Reservoir, 4 miles W. of Bolton	22,471,910	595	37,767
Ashton Waterworks Reservoir, 1½ mile N.E. of Ashton	14,436,397	378	38,453
Sheffield Waterworks— Redmires Reservoir	30,000,000	} 912	32,894
New do. do.	22,000,000		Total. 57,050

The aqueducts for passing a supply of 20 gallons per diem for each individual of a population of 500,000 may be estimated at from 400*l.* to 600*l.* per mile, according to the ruggedness of the ground and other items of expense The cost of filters upon the self-cleansing principle will average from 6000*l.* to 8000*l.* to supply the same quantity. That constructed by Mr. Thom at Paisley, which produces regularly every 24 hours a quantity equal to 106,632 cubic feet of pure water, cost about 600*l.*, and he estimates that the expense of a filter "to give a supply of water of the best quality *for family purposes*, to a town of 50,000 inhabitants, may be safely taken at 800*l.*" This supply, however, allows only 13 gallons to each individual. We prefer allowing a minimum of 20 gallons, as already estimated. Adopting the facts stated by Mr. Thom, as experienced in supplying four towns in Scotland, viz., Greenock, Paisley, Ayr, and Campbelltown, which are served by his system, but allowing the greater quantity stated, to each individual, and assuming the cost to increase in the same proportion, we find that the average annual expense per person will amount to no more that eight-pence, that is, for a regular daily supply of 20 gallons of good spring-water throughout the year. This expense includes wear and tear of apparatus, charge for superintendence, &c., and 5 per cent. per annum upon the capital employed. In the towns here referred to there is such declivity that allows of high reservoirs and constant high service to the buildings without any expenditure for power. Mr. Thom states that the cost for apparatus for the smallest of these towns, Campbelltown, of 7000 inhabitants, amounted to about 2500*l.*; or say 3800*l.*, being about 10·85 shillings to provide for the daily allowance per individual of 20 gallons instead of 13 gallons.

313. At Nottingham, about 8000 houses, or 35,000 inhabitants, are supplied with water raised from the river Trent by a Waterworks Company. The actual supply is found to amount daily to between 80 and 90 gallons per house on

an average, including breweries, dye-works, steam-engines, inns, and other places of large consumption. The levels of different parts of the town vary, perhaps, 80 ft., and the water pumped up from the river is raised above the town, so that an average pressure of 80 ft. is maintained, the greatest pressure being about 120 ft. The water is drawn from the river into a reservoir formed on its banks, and excavated in a stratum of clean gravel and sand, through which the water percolates to a distance of 150 ft. from the river. Besides the filtration which thus naturally occurs, the water is still further clarified by passing through a tunnel 4 ft. in diameter, which is laid through a similar stratum for a considerable distance up the adjacent lands, and constructed of bricks, without mortar or cement. The expenditure for the supply of these 8000 houses amounts to about 30,000*l*., and the average annual charge per house is about 7*s*. 6*d*., the water being supplied at any level required, even into the attics of four- or five-story buildings. The average daily allowance to each individual supplied is here equal to about 20 gallons; and reducing the total expenditure and the annual charge per house to an original cost and current expense per individual, as we have done in reference to the four towns supplied by reservoirs and aqueducts from surface collections and higher springs, we shall find the two items stand thus:—original cost per individual, 17·14 shillings; current expense per individual per annum, including per centage on capital, &c., 1*s*. 8*d*. The comparative statement for the four Scotch towns and for Nottingham will, therefore, be this per head of the population supplied:—

	Original cost of apparatus, &c.	Current annual expense.
	s.	*d.*
Scotch towns supplied with *drainage-* and *spring-water*	10·85	8
Nottingham supplied with *river-water*	17·14	20

The qualities of the waters, their comparative hardness, &c., should be fully known and duly estimated as items in the relative economy of the two sources

314. For the supply of some towns it will be found desirable to combine the two sources, namely, a river—and springs, or perhaps upper streams, which, flowing from lands much higher than the general level of the river, preserve a greater elevation, and may thus be applied to furnish the higher parts of the town, and effect a judicious economy of artificial power in raising the required quantity.

315. The expense of public filtering of water has already been stated, Part I., p. 65 and 67, as varying from about 2000 to 9000 gallons per penny. An average rate of 6000 gallons may be safely assumed as the quantity which can be filtered at an expense of one penny. The annual expense of filtering the supply for each individual of the population thus appears to average only 1·2 penny. This calculation is quite conclusive as to the superior economy of public over private filtering, since no separate house apparatus for this purpose can possibly be maintained in working order at this insignificant rate of expense.

316. The public filtering of water, before distributing it into the mains and service pipes by which the streets and buildings of a town are supplied, is, however, palpably insufficient to secure purity in the water as used by the inhabitants, if the quantity for each house be received and stored in a separate tank or cistern, which is seldom or never emptied or cleansed. In these receptacles the minute impurities brought in with each day's supply accumulate into a mass of growing foulness, stirred up by the daily delivery, and undergoing constant decomposition, and thus contaminating the entire contents of the cistern and every pint of water which is drawn from it. This consideration, which may be confirmed by volumes of evidence, but is too palpable to require proof, leads to the desirability of dispensing with these separate household accumulations of water, by providing a constant supply in the mains and service pipes, so that any required quantity may be at all *times instantly* commanded The supply rendered by the

Trent Waterworks Company to the town of Nottingham, and before referred to, is maintained upon this principle, the several advantages of which have been pointed out by the engineer to the works, Mr. Hawkesley, and since adopted as a general rule in the recommendations of the Superintending Inspectors to the General Board of Health.

317. The superiority of the constant service principle of the supply of water to towns over the occasional or intermittent principle is not greater in the comparative purity of the water thus obtained for the current use of the persons supplied than it is in the economy of the supply. The first cost of cisterns or tanks, with all the expensive and inefficient paraphernalia of ball-cocks, waste-pipes, &c., &c., is entirely obviated by keeping the mains, service and communication pipes always charged. It is well known that the due care and cleansing of the house-receptacles for water, whether tanks, cisterns, or butts, are greatly neglected, especially among those classes who are actively and incessantly engaged in their business or daily labours, and who are equally unable to command the services of others for such purposes. These receptacles are often imperfectly constructed and covered, open to the entrance of soot, dust, and dirt of all kinds, frequently exposed to the action of the sun, and neglected when repairs become indispensable. If these separate and inefficient means are superseded by keeping the water-pipes constantly charged, one large reservoir suffices for a whole town, or extended section of one, and this one reservoir may be so devised, constructed, and managed, that the combined supply shall be always maintained and delivered in the best possible condition. The economy of the system here advocated arises in many ways. The spaces occupied by the house-tanks are saved, and the damp which always arises from the evaporation of bodies of water is avoided, besides preventing accidents, leakage, and the occasional inconvenience of finding the cistern empty, or its contents reduced to a few inches in depth of foul mud. Another source of economy is the re-

duction in the sizes of main and service-pipes required, as the delivery is distributed over a longer period than by the intermittent supply, which limits the actual delivery for present and prospective purposes to a few hours, or some still shorter extent of time. Added to this diminution in the sizes of pipes permitted by the constant supply is the fact of their non-liability to be burst by the sudden gush of water which compresses the air within the pipes with a force which the strength even of iron cannot resist. The alternate absence and presence of water within them, moreover, hastens their corrosion, as it has been found that much oxide of iron accumulates in them under these circumstances. And beyond these advantages, the constant supply system possesses the further one of immense economy in management. It is found at Nottingham that one experienced man and one lad are sufficient to manage the distribution of the supply to about 8000 tenements, and keep all the distributory works, including cocks, main and service-pipes, &c., in perfect repair. Under the intermittent supply system, a numerous staff of assistants would be required to discharge similar duties.

318. The "Commissioners of Enquiry into the state of large Towns" have quoted a statement to the following effect:—That the expense of machinery or capital invested in the arrangements for supplying the metropolis with water, exclusive of the communication pipes to the houses, the tenants' water-butts, tanks, &c., amounts to 3,310,342*l.*, or about 3*l.* per individual supplied; that the annual income is 276,243*l.*, and the expenditure 133,724*l.*, leaving a balance which is equal to an average dividend of 4 per cent. The income from each individual supplied would thus appear to be somewhere about 5*s.* annually. Now, the metropolis is supplied mainly from the river Thames, the river Lea, and the New River, from a spring at Amwell. In the year 1843,* the entire supply was furnished by nine companies, the names of which, and the sources of their water, were as follows:—

* *For later years*, see Appendix, No. 7, p. 235.

Companies.	Sources of Water.
Chelsea	River Thames.
West Middlesex . . .	Do. do.
Grand Junction . . .	Do. do.
Southwark	Do. do.
Lambeth	Do. do.
Vauxhall . .	Do. do.
East London	River Lea.
New River . . .	Amwell and River Lea
Hampstead . . .	Springs on Hampstead Hill.

The cost of construction for the water-supply at Nottingham, as already stated (paragraph 313), is between 17*s.* and 18*s.*, and the expense attendant on the supply of water and management of the works amounts to about 44 per cent. on the income, which will be found somewhat less than the proportion of the like expense in London. The expenses both of formation of works and of current supply are evidently controlled to a considerable extent by the natural facilities for the former, and by the distance from which the water has to be conveyed and the height necessary to raise it. The expense to individuals must, of course, be also liable to be affected by the proximity, or otherwise, of the several tenants to be supplied

319. Another principle to be observed in conjunction with that of constant service of water is, that it shall be delivered from such an elevation, or with such a pressure, that the service may take place at least 20 ft. higher than the tops of the highest houses to be supplied. The vast ultimate economy and value of this provision are cheaply bought by the additional expense involved in the works, and current cost for making it. The experience of the Trent Water Company in supplying the town of Nottingham from the river Trent has shown that the expense of raising and delivering the water 50 ft. higher than at present would amount to only 5 or 6 per cent. additional upon the present cost. On the other hand, the advantages of this high service are too great to be easily calculable, saving, as

it does, all the expenses of force-pumps or other separate apparatus for raising the water from the lower floors, and affording means of supplying baths and other accessories of cleanliness, health, and comfort, to all parts of each house without restriction, labour, or cost. The total expenses of supplying water in the town referred to, with all the benefits of constant and high service, including wear and tear of engines, interest on capital for machinery and distributing pipes, expenses of management, &c., amount to 2·88 pence per thousand gallons.

320. The value of constant and high service of water to towns is strikingly important in its application for the extinction of fires, and for the occasional washing of streets, and cooling them by jets of water in warm seasons and times of drought. The bearing of these purposes upon the preservation of life and property, and the promotion of health and comfort, is too evident to need much illustration, although the details of the arrangements will claim, on account of their extended utility, some notice in our fifth section, which will be devoted to a brief account of all the essential apparatus for carrying these principles into practice.

321. Finally, let us recount the leading objects to be kept in view in the supplying of water to towns:—*First*, that the supply shall be *ample in quantity* for all the purposes of personal and domestic cleansing; for the public purposes of supplying baths, fountains, and gardens; for the extinction of fires, the thorough cleansing of streets and thoroughfares, and the occasional cooling of them in dry seasons, and for all such manufacturing purposes as may be required or permitted within towns.

Secondly, that this abundant supply should be procured of the *best possible quality* for the several uses to be made of it. That, if several sources are available at various rates of expensiveness, the economy of any one of them as compared with another, or others, is to be duly estimated, with *a governing* reference to the quality of the water so de-

rivable; and that the question of adopting an inferior water shall be affirmed only in cases where the expense of the better quality amounts to a practical impossibility. That, besides the always recognised impurities of an animal and vegetable character, and those held in mechanical suspension only, with which some waters are usually adulterated, there are others of a soluble nature, which are consequently commonly imperceptible except to chemical analysis, but the presence of which deteriorates the quality of water in a high degree, and occasions a necessity for chemical processes to purify it, mere filtering being utterly inoperative for the purpose. That, generally, these soluble matters are found in spring- and drainage-waters in far larger proportion than in river-waters, which are more susceptible of being purified by a process of self-filtration, and are, therefore, commonly preferable for most purposes to waters of the former character. That the expense of raising river-water by steam-pumping is really very small, and unworthy of consideration, although often regarded as a weighty argument in favour of seeking the required supply from districts of land from which the water descends by gravity, without artificial aid.

And, *thirdly*, that the complete utility and greatest ultimate economy of the supply of water to towns can be realised only by a service of it which is constant in duration, and sufficiently high to discharge over the highest buildings in the town.*

SECTION III.

Width and Direction of Roads and Streets.—Substructure and Surface.—Paving and Street Cleansing.

322. The drainage and cleansing of the roads, streets, and thoroughfares of a town are acknowledged to be public purposes of the highest utility. The facility of effecting these purposes is dependent upon the several circumstances

* The London and Glasgow Water Supplies are further noticed in Appendix No. 7, pp. 232—238, and Appendix No. 8, pp. 239, 240.

of the dimensions and situation, and the sub- and superstructure of the thoroughfare The width of the streets is influential in admitting or preventing the access of air and winds, by which the wholesomeness of their condition is largely affected; and also in rendering the process of cleansing by hand or other labour easy or difficult. The direction of roads and streets—vertically in their relative levels and inclinations, and, laterally, in their coincidence with or opposition to the courses of the prevalent winds—is a condition of great importance in affecting the facility and economy of the processes of drainage and cleansing. And the relative dampness and dryness and quantity of debris produced upon any public thoroughfare are mainly attributable to its construction in the subsoil, and superficial formation.

323. Courts and narrow passages, such as abound in most towns—relics of public ignorance and private cupidity, destined to be destroyed in the progress of enlightened sanatory reformation—limited in width and bounded by elevated buildings, never receive their due share of light, air, or water, and thus present the greatest combination of difficulties to the vital processes of drainage and cleansing And these purposes can never be economically and efficiently fulfilled until a minimum of width and a maximum of height of buildings are recognised as the elements of street proportion. The recorded and repeated evidence on this point is more than enough to establish the general principle, although the precision of the details requires observations of a more exact nature than have yet been made. It is certain, however, that no street should be less in width than the height of the buildings on either side of it—that is, that the angle formed by the transverse surface of the street, with a line from its extremity on one side to the summit of the buildings on the other, should never exceed 45°. And in proportion as this angle can be reduced will be the facility afforded for the desirable operation of the air and of such rain as may fall.

324. Provided this principle be strictly observed, the comparative declivity of the surface will become of minor importance. Certainly, the greater the declivity the more rapid and effective will be the action of rains in cleansing and washing down the debris upon the surface of the street; but it should be the peculiar province of the subterranean sewers constructed beneath, to compensate for the relative flatness of the surface, by affording a channel of artificial declivity, that shall at all times free the surface from these matters as quickly and effectually as possible.

325. Connected with the subject of road drainage as applicable in the suburban parts of a town, the necessity of providing *covered* drains cannot be too rigorously enforced. Open road ditches are known to become receptacles for filth and refuse matters of various kinds, and the trouble and expense of cleansing and keeping them in repair, involving a constant making-up of the banks and clearing of the beds, are commonly evaded by a total neglect, which leads to a stoppage of the channels and a constant exposure of decomposing matters, both offensive to the senses and injurious to health. These roadside ditches are frequently, moreover, adopted as the only available channels for dispersing the sewage of the suburban buildings; and being thus converted into open sewers with little or no attempt at formation, and very little care in preserving even their original rude form and capacity, the evils of retaining them are multiplied to a degree actually dangerous to the health of the inhabitants and of passengers.

326. Added to the inefficiency of open road drains or ditches is the waste of surface which they involve. Pedestrians in the suburbs of towns know well that of a narrow road nearly one-half the width is frequently occupied by a wide and sluggish ditch, and that, in the absence of any raised foot-path, they are frequently driven to a dangerous proximity to its foulness in order to escape destruction by the heedless and perhaps drunken drivers of vehicles. If

these ditches were covered and converted into active sewers by the use of pipe-tiles, of comparatively small and yet ample dimensions, space would be afforded for the formation of convenient footpaths on which a walk would become a luxury instead of being a task of danger and annoyance. Those who have "picked their way" along the unpavemented strados of Rome, and contrasted them with the easy security of some of the similarly narrow streets of our own metropolis, will readily appreciate the value of the change which might be thus cheaply effected in our suburban roadways.

327. The quantity of surface wasted by the open road ditches, and the corresponding area thus exposed for the evaporation of stagnant moisture, may be readily calculated from the dimensions of the ditch. It may be safely assumed that for each mile of road, at least half an acre of surface is thus, on an average, misapplied.

328. The position of the *main sewers* of a town being beneath and in the same direction as its streets, *these afford the proper channels for discharging the waste water and all other matters from the surface of the streets.* This doctrine is liable to be challenged by all those practical economists who contend that street debris is so injurious in its admixture with the excrementitious matters flowing from a town, that it should be scrupulously kept separate, and periodically removed by hand and horse labour above ground. But if we take into the account, on one hand, the small proportion which the solid part of this debris bears to the total of solid and liquid excrements, house refuse, street drainage, waters, &c., which are universally allowed to be the proper subjects of sewer discharge, and, on the other, form a due estimate of the inconvenience, expense, and disgusting annoyance of removing this street refuse by any expedient above ground, the result of the calculation will lead, we think, irresistibly to the conviction that the whole of these matters should be by the readiest possible

methods delivered into the sewers, and by them conveyed at once to receptacles suitable for their collection and treatment.

329 The exact proportion between the solid street refuse and the total of house-sewage and street-drainage (which may be supposed to find its way unavoidable into the sewers) is difficult to determine with any certainty approaching to exactness, but an approximate estimate may be formed from such materials as we can command. The excrementitious matters produced by each individual are generally considered to amount to an annual quantity equal to one ton in weight, and the other matters which are comprised in the total of house-sewage and street-drainage, may be supposed equal to a similar quantity. We have thus a total equal to two tons annually per head of the population. Now, in the township of Manchester, of which the population in 1841 was 164,000, the number of yards of street-surface swept in the same year was 21,500,000, and the number of loads of these sweepings removed equalled 25,029, each of which is equal to a weight of one ton. Assuming the proportion between the population and street-surface of this township to be a fair average for most towns, we have thus a total of house-sewage and street-drainage equal to $164,000 \times 2 = 328,000$ tons, and a total of street-sweepings equal to 25,029 tons, being $\frac{1}{13}$th of the former, or less than 7·7 per cent. This rough calculation will be quite sufficient to show the small proportion in which the manuring value of the sewage is liable to be injured by the admixture with it of the street debris in the common receptacles or sewers, and the consequent inadvisability of engaging in the expensive operations of carting and removing this debris by any combination of human and animal labour.

330. Arrangements for the purpose of discharging the street surface-drainage into any contiguous river or other watercourse, instead of allowing it to mingle with the sewage in the receiving wells or receptacles to which they

are both conducted by the sewers, may, if thought necessary, be provided as accessory apparatus in connection with the wells, although it is highly probable that the growth of our experience on this subject will develop preferable methods of treating and disposing of these matters by subsidence and chemical processes.

331. The amount of street debris, or the quantity removable from any extent of surface, is found to vary most materially, according to the structure of the street or roadway. Thus, roads formed of broken granite or other similar materials are rapidly destroyed by the action of wet, which loosens the superficial coating of the road, and passes into the body of the materials; the finer particles also become washed upon the surface, and act as sand in grinding it down, by the action of the wheels upon it. Paving formed with stones of irregular shapes and sizes is also productive of a large quantity of debris, although less than the unpaved surfaces just referred to; upon this inferior class of paving, water acts destructively by washing up the soil and dirt between the stones, by which they become loosened, while a great proportion of these interposed materials have to be removed as they appear upon the surface in the form of mud. Pitch-paving formed with squared blocks of granite, whin, or other stone of equal hardness and durability set in lime grouting upon a substantial foundation of concrete 9 to 18 in in thickness, according to the nature of the sub-stratum, forms the most permanent construction for the carriage-ways of streets and thoroughfares, and affords a correspondingly small proportion of materials to be removed from the surface, in order to preserve its cleanliness. Wood-paving yields the minimum of debris, and its economy, as a subject for the labours of the scavenger, at any rate, is thus very great, as compared even with the most perfect form of stone-paving.

332. By making the sewers thus directly available for one of their proper purposes, that of receiving the waste matters from the streets and thoroughfares, the operation of

street-cleansing is reduced to mere sweeping of these matters to the side channels, which should be constructed so as to afford a ready passage for them to the sewers beneath. The economy thus obtained by dispensing with the raising and carting to distances sometimes extended may be inferred from the fact, that the average expense of sweeping and carting away the refuse of 1000 square yards (in Manchester) in 1843 was 4*s.* 6*d.* This was performed by the ordinary hand labourers or sweepers. In London, at the same date, the mere *sweeping up* of the refuse from the surface of Regent Street, and depositing it in the street in loads for another process of removal, was charged at the rate of 1*s.* 2*d.* per 1000 square yards, as executed by Whitworth's patent machine. The mere *sweeping* may be liberally estimated to cost 9*d.* for the same extent of surface, and thus ⅝ths of the entire expense of street-cleansing might be avoided by adopting the sewers for the purpose suggested.

333. Although we advocate the abandonment of all apparatus for carting and removing street-refuse, it may be useful to describe briefly the "Patent Street-Cleansing Machine," invented by Mr. Joseph Whitworth, which has been applied to a considerable extent in Manchester and elsewhere, and been considered a very promising contrivance. This will be best done by quoting the inventor's own description of his machine, as rendered in evidence before the "Commissioners of Inquiry into the State of Large Towns and Populous Districts," in 1843. "The principle of the invention consists in employing the rotary motion of wheels moved by horse or other power, to raise the loose soil from the surface of the ground, and deposit it in a vehicle attached. The apparatus for this purpose consists of a series of brooms suspended from a light frame of wrought iron, hung behind a common cart, the body of which is placed near the ground for greater facility in loading. As the cart-wheels revolve, the brooms successively sweep the surface of the ground, and carry the soil up an incline

or carrier-plate, at the top of which it falls into the body of the cart. The apparatus is extremely simple in construction, and has no tendency to get out of order, nor is it liable to material injury from accident. An indicator, attached to the sweeping apparatus, shows the extent of surface swept during the day, and acts as a useful check on the driver. It also affords the opportunity of working the machine over a given quantity of surface. The average rate of effectual scavengering by hand in Manchester, taken for a whole year, is from 1000 to 1500 square yards of surface daily for each scavenger. The manner of sweeping is different in London, and therefore an apparently larger amount of work is done, but not so effectually. When the machine is in operation, the horse going only 2¼ miles per hour, it sweeps during that time 4000 square yards; thus performing in a quarter of an hour nearly the day's work of one man. The average amount of surface which can be swept by a machine during the day depends upon the distance of the places of deposit. In Manchester we have seven places of deposit, and the average number of yards swept daily, by a machine drawn by one horse, is from 16,000 to 24,000."

SECTION IV.

Main Sewers; Proportions and Dimensions, Inclinations, Forms, and Construction.—Upper and Lower Connections.—Means of Access and Cleansing.—Adaptation for Street-cleansing, &c.

334. In drainage, as in many other subjects, controversy has frequently been found to be excited upon those very details of the art which appear to be the most simple and the most readily deducible from observation, while the proper ground for discussion, in which it is really urgently needed, in order to determine general principles and mark out leading rules, has been left nearly or quite unoccupied. Thus the forms, sizes, and thicknesses of sewers have re-

ceived the most elaborate investigation, and provoked the expression of the most widely-differing opinions; while the principles of arrangement according to which the entire system should be laid out, and the great questions of the most healthful and economical disposal of the refuse of towns have, till lately, remained unsought and unasked. Misled by an instinctive adoption of the works of our forefathers, we have been content to build our sewers in old channels, and to put patch upon patch—add length to length of sluggish sewer or practical cesspool, in order to maintain ancient outfalls, while the subsidiary details of form and capacity have become the vexed questions and grounds of issue among the most practised advisers.

335. Not that the attention given to the details, and the neglect inflicted upon the general principles are here contrasted for the purpose of denying the importance of the former, but that, had the principles been first determined, the details would be found readily deducible from them in a manner and with a certitude admitting little dispute or discussion.

336. We have already, in the first section of this Division, shown the general principles upon which the drainage of towns should be arranged with reference to the inclinations of surface, and the means of discharging and disposing of the sewage. From these principles it immediately follows that the proper functions of sewers are twofold, and *twofold only*, viz., the conveyance and collection of house-drainage and of street-drainage. In the former are to be included the drainings of roofs of buildings and of yards, or other spaces attached to them. In these two purposes is thus comprised the superficial drainage of each entire town. Any attempt to add to this the drainage of the sub-formation is a mistaken and a supererogatory aim. This position will be denied by those who advocate the *under-drainage* of London as one of the purposes of its sewerage. Let us endeavour to understand the practical value of this

purpose, and thence deduce the infinitely small amount that would be mis-spent in any attempt to realise it. If the proper functions of sewers be effectually discharged, viz., the conveyance away from a town of all the rain-water that falls upon its surface, and of all the solid and liquid refuse produced in streets and buildings, what will be the amount of submoisture which it can be necessary or desirable to abstract in the form of land-drainage? The entire surface being maintained constantly dry, the only sources from which under-water can arise will be springs or water-bearing strata beneath, and wherever these may show themselves, they can be turned to good account, and the water they yield converted to useful purposes, without making expensive provision for their drainage beneath. Whatever relation the site of a town may have to the surrounding country, that is to say, whether the town be above or below the lands around, or be on a similar level, none of the drainage-water from these lands should be permitted to enter the town or to mingle with the soil beneath it. This is to be effected by constructing around the town a system of encircling catch-water drains, by which so much of the surrounding drainage as would otherwise find its way into the subsoil of the town will be intercepted and collected, either to be returned by suitable channels to the rivers, streams, and watercourses, to be made available in irrigating adjacent districts, or diverted directly from the catch-water drains into the main sewers of the town itself, and disposed of with their contents. With this auxiliary arrangement for preventing the access of surrounding drainage to the sub-formation of the town, all necessary provision for maintaining it in a dry and healthy condition will be completed, and no necessity can possibly arise for constructing a duplicate system of sewers in order to drain the subsoil of the town. With all due deference to official experience, we venture to predict that, *if ever tried*, the "system of permeable land-drains and sewers," as a sepa-

iate addition to the "system of permeable drains for house and soil drainage," will be found as utterly useless in practice as it will be expensive in construction.

337. The proportions, dimensions, inclinations, forms, and construction of main and all other sewers, are all more or less affected and determinable by the general system of drainage adopted. We will first cull from the mass of recorded experience at our command (up to the year 1843) some detailed particulars of modes of construction (and their cost), many of which have been found *inefficient* in fulfilling the *self discharge* of the sewage matters of London and other towns in England.

338. The experience in the city of London led the surveyor to the Commissioners of Sewers to consider that the form of a semicircular top and bottom, with straight (or vertical) sides, "answered all the conditions of a sewer." Nevertheless, many have been constructed of an oval form. The smallest size in a long street is 4 ft. 6 in. by 2 ft. 6 in. The other sizes are 5 ft. by 3 ft.; but several are considerably larger, where much water is expected to accrue from the outer districts. The outlet for the main sewer at South Place (Finsbury) is 6 ft. 6 in. by 4 ft. 6 in. The Fleet sewer, which *drains from the south-west of Highgate, is* 18 *ft.* 6 *in. by* 12 *ft. at the mouth, and* 12 *ft.* 3 *in. by* 11 *ft.* 7½ *in. at the city boundary; and, owing to the immense quantity of water flowing into it, "this sewer has often been surcharged."* The Eldon Street (Finsbury) sewer is 5 ft. by 3 ft. 2 in.; the London Wall sewer is 6 ft. by 4 ft., and the main trunk increases from 8 ft. 3 in. by 6 ft. 9 in. to 10 ft. by 8 ft. at its mouth. For courts and alleys the sizes are 3 ft. by 2 ft. 2 in., and sometimes, according to the number of houses, 4 ft. by 2 ft. 4 in. The sewers 4 ft. 6 in. by 2 ft. 6 in. are built in brickwork 14 in. in thickness throughout. Adapting the size of the smaller drains so as to admit a man to pass through them, they should be at least 2 ft. in width, and, to allow crawling through, 2 ft. 4 or 6 in. in height; to allow his crouching through, 3 ft. 6 in.; or to stoop through,

4 ft. 6 in. The thickness of brickwork of these sewers should not be less than 9 in., nor the depth from the ground less than 12 ft. at the shallowest part, in order to provide for the drainage of a basement story about 7 ft. 6 in. in height. Assuming 2 ft. 6 in. as the minimum height for a common sewer, and allowing 20 in. of deposit to exist in a public sewer before it can rise into the common sewers, the surveyor deduced a minimum height for public sewers of 4 ft. 2 in.

339. In the Westminster Division of Sewers the level of the outfalls into the river varies from 10 to 15 ft. below the level of high-water mark, and some of them have flaps. Some of the main sewers have *a fall of only half an inch to 100 ft.* The form of the sewers is that of a semicircular arch at the top, and a segmental invert with upright sides. The two sizes used are—first class, 5 ft. 6 in. high and 3 ft. wide; and second-class, 5 ft. high and 2 ft. 6 in. wide. The three centre courses of every invert are built in cement, and the remainder of the work in Dorking lime-mortar. The walls are 1½ brick in thickness, and the arch and invert 2 half-bricks, or 9 in. The cost for a sewer 3 ft wide was, for the brickwork, 14*s.* 3*d.* per ft., and for a sewer 2 ft. 6 in. wide, 12*s.* 6*d.*

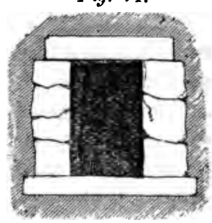
340. The sewers throughout the Holborn and Finsbury Divisions discharge into the main sewers of the city of London, and have no outfalls of their own into the Thames. The Fleet sewer conveys the drainage of about 4444 square acres of surface in those divisions, and is calculated to receive annually from this surface about 100,000 cube yards of matter held in mechanical suspension, and carried to the Thames by the force of such waters as flow through the sewer. These waters, by the experiments of Mr. Roe, having been found to amount to about 100 times the bulk of the matters held in suspension by them, it follows, that the Fleet sewer discharges from this surface about 10,000,000 of cube yards of sewage-water and suspended matters into the river Thames annually. The total

work of this sewor comprises also the quantity it receives from the surface of the city, after passing through the district here referred to. A sewer carried up to Holloway, in this division, a length of nearly 3 miles, passes under Canonbury (Islington) at a *depth of* 68 *ft. from the surface*, and the drainage of the houses in that part is provided for by a *subsidiary sewer*.

341. Sewers constructed on the Kingston estate, through a very soft clay, are built of an oval form, the largest size being 3 ft. 6 in. high, and 2 ft. 6 in. wide, the radius of the side curves about 3 ft. ; half a brick thick in cement. The extent of cutting was from 16 to 18 ft., and the cost 15*s*. per lineal foot. The fall at the rate of 80 ft in a quarter of a mile.

342. The practice in some of the provincial towns was reported as follows :—

Fig. 71.



Lancaster. — Flag or slate bottom. Rubblestone sides, laid in common mortar. Rough stone covers Mains 2 ft. 6 in. × 1 ft. 4 in., 6*s*. per lineal yard. Branch street drains, 1 ft. 4 in. square, 4*s*. 6*d*. ditto. Yard drains, 6 or 7 in. square, 2*s*. ditto. All found to be very inefficient.

Fig. 72.

Nottingham. — Brick. Cylindrical sewers. Upper half built in mortar. Lower half laid dry. Half-brick thick. Diameter from 2 ft. to 2 ft. 6 in. Average cost 7*s*. per lineal yard.

Birmingham and Walsall.—2 ft. circular culverts laid 5 ft. deep. 7*s*. per lineal yard.

Chester.—Circular brick drains from 30 to 36 in. diameter Average cost 12*s*. per lineal yard.

Bristol.—Four sizes of elliptical brick sewers.

	Ft.	in.		Ft.	in.	
1st. .	4	0	×	3	0	Internally.
2nd. .	3	3	×	2	6	
3rd. .	2	8	×	2	0	
4th.	2	0	×	1	6	

All 9 in. thick.

Fig. 73.

Cylindrical drains, 1 ft. 2 in. in diameter internally, 7 in. thick.

Rate of fall from 1 in 60 to 1 in 360.

Frome. — Stone and lime cheap and abundant. Drains or "gouts" 18 in. square, covered with stone to take any weight, exclusive of digging, 2*s*. per lineal yard.

Culverts 2 ft. square, dry walls, with rubbed stone arch, turned in good coal-ash mortar, exclusive of digging, 4*s*. 9*d*. per lineal yard.

Swansea.--Oval drains, 3 ft. 2 in. × 2 ft., including excavation, 10*s*. 6*d*. per lineal yard.

Cylindrical drains, 2 ft. diameter, including excavation, 8*s*. per lineal yard.

Brecon.—Cylindrical drains, 2 ft. diameter, cost 8*s*. per lineal yard.

Square drains, side walls of dry masonry, with flat covering stone, from 3 to 4 in. thick.

Cost.—12 in. 2*s*. 6*d*. per lineal yard.
15 in. 3*s*. 3*d*. „
18 in. 4*s*. „

343. The egg-shaped or oviform section used in the Holborn and Finsbury divisions is shown in fig. 74, and the section commonly used in the Westminster division, up to the year 1843, is shown in fig. 75. The difference in expense between sewers of these sections has been estimated at 1660*l*. per mile, upon the following data. Brickwork at

20*s*. per cube yard. Excavation 1*s* per cube yard. Filling in 3*d* per cube yard. Carting 2*s*. per cube yard. Remaking

Fig. 74.

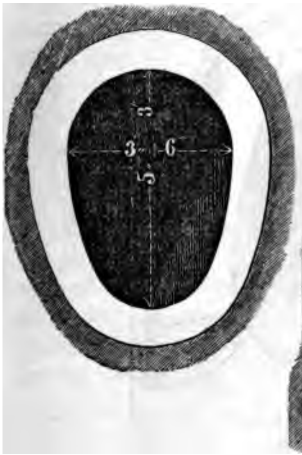
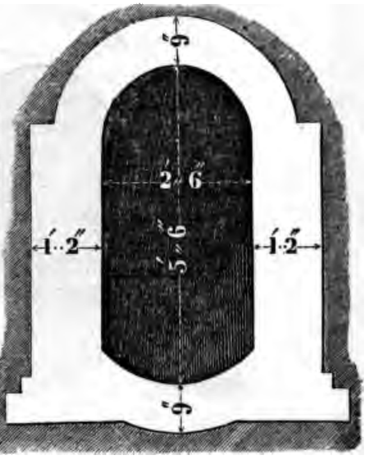


Fig. 75.



surface 1*s*. 6*d*. per superficial yard. Average depth of excavation, 20 ft. The quantities per mile of each sewer are shown in the following table; the size of the egg-shaped sewer being 5 ft. 3 in. by 3 ft. 6 in.. and that of the upright-sided sewer 5 ft. 6 in. by 3 ft.

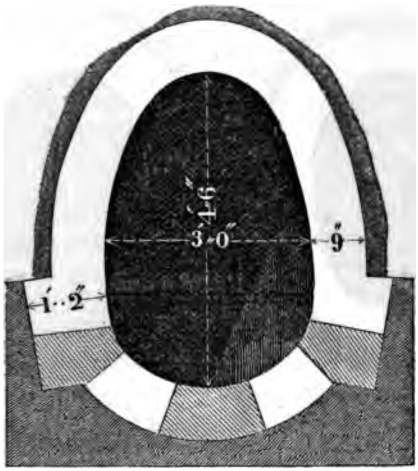
	Finsbury, or Egg-shaped Sewer.	Westminster, or Upright-sided Sewer.
Bricks consumed	924,140	1,378,080
Cube yards of brickwork . .	2,272	3,388
Do. do. of excavation . .	19,555	25,420

Excess in Westminster Sewer, per mile.

1116 cube yards of brickwork at 20*s*. . .	£1116	0	0
5865 „ „ excavation at 1*s*. . .	293	5	0
5865 „ „ filling-in at 3*d*. . . .	73	6	3
1116 „ „ carting at 2*s*. . . .	111	12	0
880 super yards repairing at 1*s*. 6*d*. . .	66	0	0
Total	£1660	3	3

344. One of the Westminster sewers, built in the Harrow Road, according to the section, fig. 75, failed, owing, as

Fig. 76.



alleged, to some difficulties in the nature of the soil, and to imperfect workmanship. This was replaced by another form of sewer, which is shown in fig. 76, in which the shaded parts represent brickwork in cement, the invert and springers being bedded in concrete as high as the 14-inch work, as there shown.

345. The *capacity* of sewers is determined by a consideration jointly of the *quantity* of sewage to be conveyed through them, and of the rate of inclination or *fall* in their vertical position. The capacity will vary directly as the quantity and inversely as the fall; since the greater the fall the more rapid will be the discharge. It has been usual to prescribe another limitation as to the minimum capacity of sewers, viz., that they shall at least, under all circumstances, be large enough for a man to pass along them. The necessity for this allowance has arisen from the fact, that sewers are found to require cleansing by hand—that it

is utterly impossible to remove the accumulations which are liable to occur within them by any other means, and thus some 10,000*l.* has been annually expended in London alone in an employment of a most disgusting and dangerous nature. We have no hesitation in saying, that, under a thoroughly efficient and practicable system, no such process could ever be needed, and, moreover, that if deemed desirable for any possible purpose, it would apply only to the principal sewers, the size of which would admit of it, as determined upon the joint data of *quantity* and *fall alone* We will, therefore, dismiss this condition from the problem, and study it upon the two data named.

346. Since the quantity of sewage due to any given extent of surface will depend mainly upon the amount of population to be served, it follows, that in an equalised system aiming at an uniform size for the sewers of the several classes, the points of collection or receiving wells should be arranged at distances varying inversely as the density of the population. Now, the *maximum* density of the population of London is estimated at 243,000 to a square mile. Let us suppose the drainage of one quarter of a square mile of surface, populated to this extreme degree of closeness, to be conveyed in *one main sewer*, and endeavour to form a rough notion of the total quantity of sewage which this sewer should be fitted to convey and discharge. The entire bulk of sewage must consist chiefly of the house-sewage and rain-water from the surface—at least the other constituents are of too insignificant an amount to require notice in a merely approximate estimate. And similarly the entire house-sewage may be assumed as equal to the bulk of water delivered to the total population. We have calculated, in Section II., on the supply of water (par. 283), that 20 gallons are, or ought to be, allowed to each individual of the population per diem. The annual quantity will, therefore, be 20 × 365 = 73,000 gallons, or say 1200 cubic feet. The population of the square quarter

of a mile being $\frac{243,000}{4}$, or about 60,000, this number multiplied by 1200 cubic feet for each person will produce 72,000,000 as the annual quantity of sewage in cubic feet arising from this population. To this is to be added the bulk of the rain-water, which we will allow to amount to 24 inches, or 2 ft., in depth annually over the surface, and that this quantity will be discharged into the sewer without further diminution by evaporation. The total quantity to be drained annually from the surface of the quarter of a square mile will thus amount to $2640^2 \times 2 = 13,539,200$ cubic feet. Adding this, which we will call 13½ millions, to the 72 millions of house-sewage, we obtain a total of 85½ millions of cubic feet of sewage to be discharged per annum from the surface of a square mile of the most densely-populated part of the metropolis. If this annual quantity were in a state of constant transition along the sewer, and with equal velocity throughout, and the effect of friction was for the moment disregarded, the proportion to be passed per minute would be of course easily calculated, being 85,500,000 divided by 525,600 (the number of minutes in a year), or 162·66 cubic feet. Now a recorded fact will be a more useful datum for our calculation here than any elaborate investigation of velocities, friction, &c.; and we will, therefore, refer to the experiments of Mr. Roe, instituted for testing the value of the flushing system as applied to sewers, and which showed that the sewage passed through the river Fleet sewer with an average velocity of 83·47 ft. per minute; the run of water being spread over a surface 10 ft. in width, and the stream being only 10 in. in depth, the passage every minute, therefore, was equal to 692·8 cube feet of sewage, and the friction in this case being greater than if the same sectional area of water had been accumulated in a cylindrical drain of smaller diameter. The solid matters held in suspension by this water amounted to the proportion of 1 in 96 of the bulk of water, and consisted, as all sewage usually does, of decom-

posed animal and vegetable matter, and detritus from streets and roads. At this rate of transit, it appears that a sectional area equal to two square feet would suffice to pass the entire sewage of a thickly-populated area of a square quarter of a mile, supposing the passage to be constant and uniform, and the fall of the sewer and friction of the sewage equal to that of the river Fleet sewer, on which the experiments were made.

347. In modifying this result to provide for the difference between the assumed and the real nature of the transit, we will first admit that the bulk of the sewage, consisting of that flowing from the houses, is delivered into the drains during perhaps half the real time; that is, during 12 instead of 24 hours. The sewers will, therefore, be required to discharge double the quantity estimated during each alternate period of twelve hours, and during the intervening periods of like extent to remain empty. We will, therefore, double the capacity, and allow four square feet of transverse sectional area of main sewer for the drainage of the given surface.

348. But we have another allowance to make; we have the "*storm* waters" to provide for, about which we have heard so much, because occasionally, during the rainy month of July, a smart shower is observed to cover a flat street, or form ponds on the low side of an ill-formed roadway. Let us estimate the allowance required for this phenomenon, and infer the advisability of providing for it in the sewers. We have seen that 24 inches in depth of rain falling upon our selected spot will equal a total bulk of 13½ millions of cubic feet. We will suppose an extraordinary case, viz. that some July day the whole quantity due to a month (2 inches) falls in 20 minutes. Then, in order to prevent any flooding of the thoroughfares, this quantity, equal to $\frac{13{,}500{,}000}{12} = 1{,}125{,}000$ cubic feet, will have to be disposed of in 20 minutes. Assume that the velocity produced by the pressure on the water will equal 1000 ft.

per minute What would be the capacity of the sewer equal to discharge this rain-water as rapidly as it falls from the clouds? The quantity accruing per minute being $\frac{1,125,000}{20} = 56,250$ cubic feet, and the velocity equal to 1000 cubic feet, the capacity of the sewer must be equal to 56¼ square feet of transverse sectional area. Now, we have found that an area of 4 ft. will suffice ordinarily for the house-sewage. Is it desirable to increase the capacity of our sewers *fourteen fold* in order to provide for an occasional shower? There can be no necessity to answer the query. Economy of the most liberal disposition would not sanction any such arrangement. If the exact area of 4 ft. be doubled, in order to make ample provision for all ordinary contingencies, it will satisfy every reasonable requirement; and then, by suitable inlets to the sewer, the deluge of rain-waters will be prevented from overcharging it, and the effects of the shower will disappear in some hour and a half, and before any very serious mischief can be produced by the water soaking into the subsoil through well-paved streets and yards.

349. In proportion as the population is more extended, the ratio of house-sewage to surface-sewage will of course diminish, and *vice versâ;* but we believe that economy and facility of drainage will be best promoted by limiting the sum of population and area to each receiving well, so that a transverse sectional area of 8 or 9 ft. shall suffice for the main sewers.

350. In the suburban districts of a town, where comparatively large surfaces exist in gardens, and where, therefore, the effect of allowing the "storm waters" to gather might be productive of mischief by saturating the soil, the diminished amount of house-sewage will tend to make the operation of the mains more effective in relieving the surface, besides which, natural declivities will usually aid the fall of the sewers; and provision might frequently be made *at little cost* for receiving the surface-water in auxiliary

wells or receptacles in which it could be made available for subsequent service in irrigation, without allowing it to burden the main sewers of the district.

351. Having based our calculation as to the capacity of main sewers upon an area of the maximum density of population, we will, with the same view of providing for the utmost necessities, consider the question of declivity or fall as to be applied to that description of natural surface which presents the greatest difficulties to the operation of any system of sewage—a perfect or dead level. The wells or receptacles for the sewage being placed half a mile distant from one another, so that the area drained into each of them equals a square quarter of a mile (or each side 2640 ft. long), half of this, or 1320 ft., may be taken as the length of each of the main drains. The longest of the main sewers thus measuring 1320 ft., the fall is to be computed with reference to this length. We have seen that metropolitan sewer-practice has recognised a fall of half an inch in 10 ft., or 1 in 240, as sufficient for all the purposes of good drainage. At this rate the fall due to 1320 ft. will be 5½ ft. But preferring to allow double this fall as proportionally improving the system, by aiding the discharge, we should require a fall of 11 ft. in our main sewers of the maximum length. And preserving 5 ft. above the head of the main, it would lie at a depth of 16 ft. at the well. This 5 ft. will usually be found sufficient to allow all necessary fall in house-drains and in branch sewers, to serve the *superficial* draining of the intervening district.

352. The utmost economy of the system would be attained by multiplying the main sewers as much as possible, as by this means the length of the branches may be reduced to a considerable extent, and the necessary depth of the mains also reduced correspondingly. On the other hand, by sparing the main sewers, they are required to be laid deeper, and the branches also; or, if depth be saved, it is at the expense of efficiency, and the whole system is instantly filled with insuperable difficulties in vain attempts

to reconcile the relative levels of an infinite number of collateral sewers, and to adjust the details of the arrangement to the minor variations of surface above.

353. In the depths we have assumed, as deduced from the desirable rate of inclination for the main sewers, allowance is not yet made for draining the basement stories of the buildings. It must be confessed that this purpose involves the greatest difficulty in the details of the system. On the one hand, it is evident that the construction of sewers as large as rivers, and at depths varying from 20 to 70 ft. below the surface, demands a most extravagant expenditure at the outset, and, after all, puts the works in positions which are practically inaccessible. Yet, on the other hand, we shall be reminded that the deep basements and kitchens must be provided for, and that our branch sewers must be sunk low enough to serve even the lowest of these. In order to provide for these, the main sewers will need to be laid some 8 or 10 ft. lower than the depths we have given, viz., 13 or 15 ft. at the head, and 24 or 26 ft deep at the well. Rather than permit the evils caused by sinking sewers at these depths, it will probably be preferable to reduce the distance between the wells, or even admit (although highly objectionable) some diminution in the rate of fall. We are satisfied, however, that the fullest investigation into this subject will establish the principle *that no sewage matters of any kind whatever should be allowed to be discharged into a drain from any rooms or apartments below the surface of the ground.* The difficulties which would attend any attempt to carry this principle into effect in London and similarly ill-constructed cities, may be too formidable to be now encountered, but they must be overcome before the sewerage of such towns can be reformed upon the most efficient plan which our present knowledge and experience suggest.

354. The dimensions of the branch sewers are to be determined upon the same two elements of population and surface to be served that we have referred to in estimating

the required capacity for the mains; and, according to the varying extent and proportion of these elements, a scale of sizes may be determined for the several lengths, distances apart, &c., of the branch sewers.

355. By the system of district collections here recommended, one great difficulty felt in planning sewers for concentrated discharge is at once obviated. In forming sewers which are intended at the time to serve a certain district, but which may hereafter be treated as trunks, and called upon to discharge constant accessions of sewage from an extending neighbourhood, no calculation can possibly be made as to the sufficiency or otherwise of the section it is proposed to adopt. Thus, as truly remarked by the Surveyor to the City Sewers Commission, "the sewer from Moorfields to Holloway appears to measure upon the map about *three* lineal miles. In process of time, and as buildings increase, it may throw out branches in all directions, and the *three* miles may become *thirty*. Not only all the atmospheric waters which may, upon an average, fall within the valley south-eastward of Highgate (or at least a large portion of them), but all the artificial supplies which the wants of its yet future inhabitants, as well as of those intermediate between Islington and Moorfields, may require, will have to be carried off by the City sewers." The necessary consequence of which doubtful condition is, either that the sewers are at first constructed in a most extravagant manner as to dimensions and depth, or that they are afterwards found to be utterly inadequate to their increased duty, and have to be reconstructed at greater depth and of enlarged capacity. Whereas, if district collections are adopted, each main sewer is at once properly devised as to size, form, and construction, and continues to perform its services efficiently; and, as new districts are formed, each of them is provided with another system of sewers adapted to its defined limits, and made sufficient for all the work it will be ever expected to perform.

356. In the *form* of sewers two conditions have to be

fulfilled, viz. *strength*, as obtained with economy of cost, and *efficiency of action*. A hollow channel embedded in the subsoil is evidently liable to be pressed upon and against by the weight and bulk of the surrounding solid materials, and it therefore becomes necessary that the form of this channel be such as will enable it to resist effectually this pressure from without. We all know that a curved form of construction, in which the convex surface is opposed against the pressure, is stronger in this way than a plane surface, because the pressure applied to any point of the convex surface is immediately distributed to all the surrounding points on that surface, and their combined resistance is thus brought into action against the external force. And since the complete co-operation of all parts of the surface in resisting *uniform* pressure from the exterior is obtained only when all those parts have a common centre, the circle is the most perfect figure for this purpose.

357 But the pressure upon all parts of a sewer is not uniform. The top of it will be subject to the entire weight of the mass above it, minus only the friction and structural tenacity by which that mass is prevented from moving freely downward from the surrounding portions. The sides of the sewer are pressed against by the soil with forces inversely proportional to the tenacity of the material; that is to say, the less the tenacity or power of self-support, the greater will be the pressure against the sewer. The bottom of the sewer may be regarded as free from external pressure, except such as is due to the resistance with which the soil below meets the downward pressure exerted by the sewer itself, and transmitted by it from the load above.

358. The greatest pressure being thus vertically from above, a form of uniform strength would require to act with greater resistance in this direction. Hence an elliptical form, the longest diameter being placed vertically, would appear to answer the conditions better than a circle, *and is, doubtless*, the least imperfect form that can be

adopted. Practically it has been deemed desirable to combine, as far as possible, a considerable capacity with the means of making a reduced flow active in its passage through the sewer; and these requirements appear to be fulfilled by a form of section that differs from an ellipse in having the upper curve of larger radius than the lower one, resembling the outline of an egg standing on its smaller end, and to which the name of egg-shaped, or oviform, has therefore been applied.

359. The value of the curved bottom of reduced radius depends upon the well-known law, that the passage of fluids through channels is retarded by the friction between the water and the surface of the channel with which it is in contact. And it is an evident result of this law, that the greater the surface of contact the greater the friction. Hence any given bulk of water will flow the most rapidly in that form of channel in which this surface of contact is reduced to the minimum. The form necessary to fulfil this condition is presented at once by the well-known geometrical principle, that the circle includes a greater area within its perimeter than any other figure of equal perimeter. And as the necessity for aiding the flow by diminishing the friction occurs chiefly when only a small stream exists within the sewer, it follows that the radius of curvature should be proportionally reduced within practical limits.

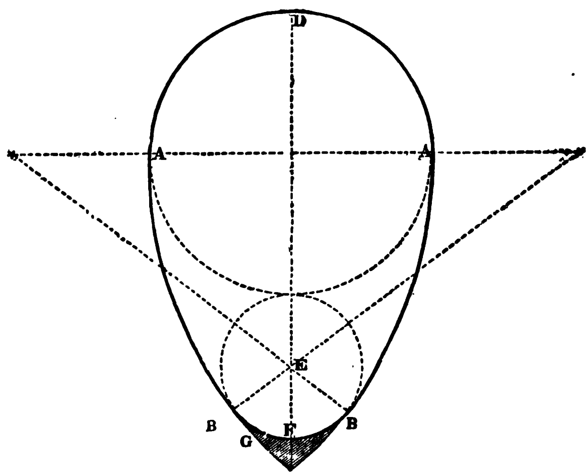
360. The exact proportion which the radii of the upper and lower curves of the oviform section of sewer should bear to each other, (adopting circular curves as preferable in practice to elliptical or any indefinite curves,) would depend on the precise average minimum of water to be provided for, calculated jointly with the density and tenacity of the soil, and the depth at which the sewer is laid As it is manifestly impossible to determine all these elements with exactness in evolving any general rule for the proportions of the section, they may be disregarded, since the main form is established by the conditions stated in

paragraph 358, and a practical rule may be formed which will be found to answer all real purposes.

361. In the forming of sewers, as in all works of a similar class, which are often necessarily entrusted, to a great extent, to the charge of workmen, who cannot be expected to pay much attention to the refinements of geometrical principles, *simplicity* is evidently an object of the first importance. The proportions of the several curves required in marking out the section and forming the moulds and gauges to be used in constructing and testing the work should be such as can be readily understood and exactly remembered; and in proportion as these rules are observed in designing the form, will be the probability of that form being preserved, and exactness attained in the construction of the sewer.

362. In seeking this object we have worked out a diagram of proportions, shown in fig. 77, that we can venture to

Fig. 77.



recommend on the score of simplicity and sufficiency, which we hope will be made evident by the figure and the

following description. In this section let the diameter A A, of the upper semicircle A D A equal 1; that of the lower arc B B will equal ·5. The entire height of the section D F will equal 1·5, and the radius C A A, of the side arcs A B (truly tangential to the upper and lower arcs) will also equal 1·5. The centres C C being upon the produced diameter of the upper arc, that arc will equal a semicircle, and the lower arc B B will equal 120°, the points for the meeting of the curves being at B B, found by drawing the radial lines, C B, through the centre E of the lower arc. Suppose the greatest diameter A A be determined at 3 ft., the several dimensions will be thus:—

	Ft.	In.
Diameter of upper arc	3	0
Do. of lower arc	1	6
Height of section	4	6
Radius of side arcs	4	6

And the area may be taken (as a very close approximation to the truth) as equal to that of a semicircle of 3 ft. diameter, added to the area of a circular segment whose radius is 4 ft. 6 in., and versed sine 1 ft. 6 in.; the area thus given being in excess only the small space shown in shaded lines at G.

363. The *construction* of sewers is varied according to their size, and should be also considered with reference to the economy with which different materials may be obtained according to the locality of the district, and also the nature of the soil in which the work is constructed. For the smaller sewers the "glazed stone-ware" pipes are found efficient substitutes for those built up of brickwork. They have the advantages of being much more quickly laid than the others can be built, and of presenting a very superior surface for the rapid passage of the sewage. They are also constructed in various forms of bends and junction pieces, and thus afford the means of ensuring proper form in these points. From their comparative thinness, pipes of this kind afford a much larger capacity with a given quantity of

excavation for laying them, than sewers formed of brick-work, which, even for the smallest diameter, cannot be less than half a brick, or $4\frac{1}{2}$ in. in thickness. In laying them care must, of course, be taken with the joints, which are formed by a socket on one end of each length of pipe in which the plain end of the adjoining length is received. The prices at which these pipes may be procured in London are as follows:—

Straight Tubes with Socket Joints.

	Inches Bore.	Price per Lineal Foot. s. d.
In 3 ft. lengths	2 . .	0 4
" "	3 .	0 5
2 ft. "	4 . .	0 6
" "	6 . .	0 8
" "	9 . .	1 $1\frac{1}{2}$
" "	12 . .	1 10
" "	15 . .	3 0
" "	18 . .	4 0

Diameter of Bore.	Bends Each.	Junctions Each.	Double Junctions Each.
Inches.	s. d.	s. d.	s. d.
2	1 0	1 0	1 4
3	1 3	1 3	1 8
4	1 9	1 6	2 0
6	2 3	2 0	2 8
9	3 6	3 6	4 6
12	5 6	5 6	7 0

Egg-shaped tubes are also prepared of the same material in 2 ft. lengths with socket joints, at the following prices:—

Size Inside. Ft. In. Ft. In.	Price per Lineal Foot. s. d.
1 8 × 1 0 . .	3 6
1 3 × 0 9 . .	2 3
0 9 × 0 6 . .	1 1

In Chester the following prices have been paid, including excavation of the maximum depth of 12 ft. :—

Inches.	s.	d.		
42 × 32	11	0	per lineal yard,	ordinary earth
42 × 32	15	2	„	rock.
36 × 28	9	6	„	ordinary earth
33 × 25	8	6	„	„ „
30 × 22	7	9	„	„ „
24 × 18	6	6	„	„ „
20 × 15	5	6	„	„ „
15 × 12	4	9	„	„ „

The stone-ware tubes may be manufactured with ample strength for all purposes required in their application as minor sewers. Some experiments, made with specimen tubes of fire-clay at Glasgow, proved their power to resist a pressure equal to that of a perpendicular column of water 900 ft. in height, being three times the pressure to which it is found necessary to prove iron pipes used for the transmission of water. Drain tubes of common clay are supplied in Glasgow at the following prices:—

	s.	d.	
3 in. diameter	0	6	per lineal yard.
6 „	0	9	„
9 „	1	0	„
12 „	1	3	„
18 „	2	0	„

Pipes of fire-clay at Glasgow, cost —

	s.	d.	
4 in. diameter	1	0	per lineal yard.
6 „	1	6	„
12 „	2	3	„

Supplied in large quantities, it is presumed that all of these prices for tubular drains would admit of considerable reduction. The following estimates for works, as ordered by the Metropolitan Commission of Sewers in the months

of April and May, 1849, contain some useful figures as *to the cost of works of this class:—*

Quantities.	Localities.	Estimated Cost. £	s.	d.
245 ft. of 12 in. pipe sewer . .	To be put down an open sewer in Southampton Street, Nine Elms, Surrey .	39	0	0
400 ft. of 9 in. and 500 ft. of 12 in. . .	To be put down in St. Mark's Road, Kennington	131	5	0
485 ft. of 12 in. . .	To be put down in James Street, Kennington	78	16	3
400 ft. of 9 in. and 415 ft. of 12 in. . .	To be put down on the south side of Kennington Common	117	18	9
700 ft. of 4 in. . .	To be put down on the north side of Kennington Common	15	0	0
483 ft. of sewer, 3 ft. 6 in. by 2 ft. 3 in.	To be put down in the Wyndham Road, Camberwell	157	0	0
95 ft. of 18 in. pipe sewer	To be put down in Great Guildford Street, Borough	28	10	6
135 ft. of 15 in. . .	. . . .	26	0	0
665 ft. of 9 in. . .	In an open ditch	78	10	0
800 ft. of half-brick sewer, 3 ft. 6 in. by 2 ft. 3 in. and 158 ft. of 12 in. pipe sewer	. . . .	300	0	0
240 ft. of 9 in. . .	. . . .	15	0	0

From these estimates the average costs of supplying and laying the pipe sewers of several sizes appear to be as follow:—

	s.	d.	
4 in. . . . . . . :	0	5·14	per foot.
9 in.	1	3	,,
12 in.	3	3	,,
15 in.	3	10	,,
18 in.	6	0	,,

And of the egg-shaped sewer, half a brick thick, and measuring 3 ft. 6 in. by 2 ft. 3 in., 6*s*. 10½*d*. per foot.

364. In commonly good soils brick sewers may be constructed of a single half brick, or 4½ in. in thickness, of curved form, of considerable size. In the Finsbury division, half brick egg-shaped sewers have been constructed, 4 ft. *6 in. by 2 ft.* 9 in., and are found sufficient. Sewers of

these dimensions would be ample for the mains of properly limited and defined districts. If the soil be of a loose and uncertain character, it will be necessary to build them 9 in. in thickness, or two half-brick rings. In the small curve of the invert all brick-built sewers should be very carefully constructed, the unavoidable interstices between the bricks (if of the common square form) being filled in with pieces of slate or tile, and the whole floated in with cement to make it as one solid mass. If this be not honestly done and carefully superintended, the action of the declivity will be nullified by irregularities in the interior surface of the waterway, and a liability created to the formation of bars by the settlement of the solid portions of the sewage. Egg-shaped sewers 3 ft. 6 in. by 2 ft. 6 in., in an average excavation of 15 ft., have been executed at a cost of about 14*s*. per lineal foot in the neighbourhood of London. These sewers were built half a brick in thickness and in cement throughout, and the cost included excavation and refilling the soil.

365. Egg-shaped sewers formed according to the rule given (362), built half a brick in thickness and with inverts in cement, in an average excavation of 10 ft., may be estimated to cost per lineal foot as follow:—

	Ft.	In.		Ft.	In.	*s.*	*d.*	
Class 1	4	0	×	2	8	10	0	per lineal foot.
„ 2	3	6	×	2	4	8	6	„
„ 3	3	0	×	2	0	7	0	„
„ 4	2	6	×	1	8	5	6	„
„ 5	2	0	×	1	4	4	6	„

366. In forming the connections of drains with each other, viz. those of the house drains with the branch drains or sewers, and of these with the mains, through the several classes of sizes which it may be necessary to adopt, two rules should be in all cases imperatively insisted upon,— first, that all junctions shall be formed with curves, and of as large radii as possible in the direction of the current;

and, secondly, that wherever a minor drain discharges into a larger one, the bed of the former shall be kept as much as possible *above* that of the latter as the relative sizes of the two sewers will admit

367. The importance of the first of these rules has been long recognised and admits of proof, both theoretical and practical. It is found that in a sewer of 2 ft. 6 in. in width, a stream of water, flowing with a velocity equal to 250 ft. per minute, meets a resistance in suffering a change of direction, the amount of which depends upon the directness with which that change is made; the resistance occasioned being three times as great by a right angle as by a curve of 20 ft. radius, and double that produced by a curve of 5 ft. radius. The resistance thus diminishes as the radius of curvature of the junction is increased. The effect of junctions in which considerable resistance is opposed to the free passage of the sewage is, that the solid particles become deposited, and, being left by the flowing water, they accumulate until a bar is formed, which still further impedes the progress of the sewage, and eventually arrests it altogether.

368. The practical value of keeping the mouths of minor sewers above the level of the bed of the mains into which they discharge, arises from the prevention by this means of a return of the sewage up the minor drains, supposing a deficient declivity or any untoward circumstance should produce a retrograde movement within the main. The connection should also be formed in the most perfect manner, so that the mingling of the currents shall not have the effect of impeding either of them. The mouth of the minor drain should be spread into a bell-form, and the whole surface of the junction made solid and even with good cement.

369. The upper connections of the minor sewers, viz with the house drains, are small works, requiring the greatest care and circumspection. They are frequently *disregarded* and carelessly executed, because they appear

individually trivial matters; and, moreover, are troublesome and tedious, and correspondingly expensive. But it is clear that the efficiency of the entire arrangement of any system of town drainage is primarily dependent upon the completeness with which the individual drains of houses convey the separate contributions of sewage into the minor or branch drains. If these tributaries fail, the trunk of course remains idle, and all care bestowed on the larger works is thrown away. Supposing the house drains to be formed with clay or stone-ware pipes, and the receiving branch sewer to be of the same material, lengths of the latter should be introduced at intervals having sockets into which the ends of the house drains may be fitted. If the branch sewer be of brickwork, the junction of the house drains should be carefully made good with a ring of cement, and the work nicely finished on the interior surface. It will of course be necessary to lay these house drains and branch sewers at the same time (if the latter are of brick work and not large enough to admit a workman), in order to complete this work in the best manner. And as this is not always convenient, the stone-ware pipes offer the great advantage of jointing without any hand work inside the branch, by simply laying the branch sewers with sufficient socket outlet lengths at intervals, which may be communicated with by house drains at any future time, the sockets being temporarily plugged up with wood.

370. The lower ends of the main sewers will communicate with the receiving wells, and should be well lipped downwards to promote the ready discharge of the sewage the moment it arrives at the mouth. These being principal works, and few in number, are more likely to be well attended to and carefully executed than the multiplied minor connections. The wells, adapted in capacity to the quantity of sewage they are intended to contain, will require substantial and sound work. Being in towns necessarily sunk to some depth in the ground, the cylinder will be the best form in which to construct them. Behind and around the

brickwork a backing of concrete should be filled in, the excavation being made sufficiently large for this purpose, and the whole interior surface should be lined with cement or asphalte. If this be done it will not be necessary to build the work in cement, although this would, perhaps, be a wise additional precaution. Proper economy in this matter will be best arrived at by experiments, upon which an adequate sum of money would be well expended before extensive operations are commenced.

371. Means of access to the main sewers are best afforded by side entrances, such as those which have been introduced in the Holborn and Finsbury division for the purposes of inspection and flushing. Although, if the entire system were properly constructed, no necessity could occur for artificial cleansing, it will be desirable to provide means of getting at the interior of the main sewers at intervals, and the side entrances referred to are well adapted for this purpose. The side entrance consists of a vertical square or rectangular aperture, formed in brickwork, and covered by a hinged iron cover, fitted in the foot-pavement of the street. This aperture is carried down to a level of about 2 ft. above the bed of the main sewer, and terminates in a short passage or tunnel, which opens into the side of the sewer. The vertical entrance is provided with hand-irons, built into the wall, by which descent and ascent are rendered easy.

372. We have already insisted on the necessity of so arranging and constructing the sewers of a town that they shall not require any cleansing by hand, and have denied the condition of admitting workmen as an essential one in determining the size of sewers. A sewer cannot be considered as properly constructed if it retain the matters committed to it in a quiescent condition. It should act simply as a place of passage, and instantly transfer the sewage onward towards the receiving well. Failing in this purpose, and containing all the solid matters in a constantly-growing accumulation, the sewers of a town act as

combined cesspoöls, and the several gully-holes serve as the outlets for the escape into the atmosphere of some of the deadly gases constantly engendering below The expense of cleansing by hand is, moreover, an item of considerable importance, although, of course, never incurred until the subterranean nuisance becomes intolerable. In the Holborn and Finsbury division, the cost of removing the soil from the sewers provided with man holes is about 7*s.* per cubic yard, and from those without, 11*s.* per cubic yard, including the expense of breaking the arch and making it good again.

373. The method of cleansing the sewers in which matter accumulates, by flushing water through them, was practised to a great extent in the Holborn and Finsbury division of sewers, and has been adopted by the New Metropolitan Commission of Sewers. The principle of this method consists simply in retaining the sewage water for a period of time by flushing gates fitted in the sewer, and periodically admitting the accumulated water to pass by opening the gates, and thus producing an artificial rush sufficient to carry all accumulations before it. The relative economy of the process, as practised in the Holborn and Finsbury division, and, as compared with the hand cleansing, was stated as follows:—

	£	*s.*	*d.*
Washing away 6688 cubic yards of deposit by board-dams (a process always performed preparatory to fixing and using the flushing apparatus)	644	12	7
Putting inside entrances and flushing gates	1293	0	0
	£1937	12	7

The cost of removing these 6688 cubic yards by hand would have amounted to 2387*l.* The preliminary cleansing and providing flushing apparatus were, therefore, effected at a saving of 449*l.* 7*s.* 5*d.* The current expenses of the two methods are thus stated:—

	£	s.	d.
Annual cost of cleansing 16 miles of sewers by hand	326	17	0
Annual cost of cleansing 16 miles of sewers by working flushing gates . . .	106	0	0
Annual saving by flushing method	£220	17	0

The cost of this method, as subsequently practised under the New Metropolitan Commission of Sewers, has been reported as being about one-third that of cleansing by hand; thus 22,400 ft. of sewers, in which the deposit varied from 6 in. to 3 ft 6 in. (in depth) were cleansed, and 3386 double loads washed away at an expense of 500*l.*, which process, under the old system, would have cost 1500*l.*

374. The method of flushing is attended with one, and that a very serious, evil consequence, and the mischief of which is the greater in proportion to the force and velocity, and corresponding efficiency of the process. This is, the violent driving forward of the foul gases with which the otherwise vacant portion of a sewer holding stagnant refuse is usually filled. The flushing of the higher part of an extended line of sewer is thus frequently productive of a rising of these gases into the house-drains connected with the lower portion of the sewer, and any imperfection in the trapping of these admits the most noisome effluvia into the houses, while the streets are always poisoned with the gases thus driven up through the gratings and gully holes. Sometimes, indeed, the flushing water is forced into the house-drains, and, of course, occasions a total suspension of the flow of the sewage in the reverse direction. Accordingly, we find that the process of flushing has been discontinued during the warm season, the very time when it is most needed as an artificial means of cleansing the sewers.

375. For the efficient cleansing of the streets and thoroughfares of a town two provisions are requisite, viz. *an abundant* supply of water for occasional application,

when the self-supply of rain is suspended, and a complete arrangement of sewers through which to discharge all the surface-water when its purpose of cleansing has been fulfilled. For the supply of water, the system of constant supply affords the greatest facilities, giving an instant command of the required quantity.

376. It has been ascertained in London, that one ton of water is sufficient to lay the dust over a surface of 600 square yards of gravel or macadamized roads, or of 400 square yards of granite paved streets. The average number of days per annum in which it is found, from twenty years' experience, to be necessary to apply water for this purpose, is about 120. The common charge for this work is at the rate of $\frac{3}{4}$*d.* per square yard for the season, the water being applied only once per diem, or 50*l.* per mile of a main road. The common assessment per house for watering roads twice a day is 1*l.* for the season. The cost of doing the same work by means of jets, supplied from the main water-pipes, is estimated at 5*s.* per house. At Nottingham, where the constant service of water is rendered, a charge of 7*s.* 6*d.* per annum is made for a single street plug, by which some of the proprietors of shops command a ready supply, at all times, for watering the street in front of their own premises, and often of the adjoining houses also.

377. The scouring effect of jets of water thrown upon the surface of the streets is far greater than when merely dropped or thrown from the perforated pipe of a water-cart. A single jet, supplied with a force equal to throw the water vertically upward to a height of fifty feet, will, directed at an angle of 45°, command an area of about 2000 square yards, and this surface will be really cleansed by the process, whereas the mere distribution of the water, without pressure, wets without cleansing. The mud which is formed on the surface of the streets, during certain states of the weather, is well known to have an unctuous character, which resists all cleansing action less vigorous than that of jets of water under pressure

378. The position of the main sewers beneath the streets of a town affords ready means of directly discharging the waste waters from their surface. The adaptation of the sewers for this purpose requires inlets, at intervals, fitted with iron gratings, by which large substances are prevented from passing into the sewers. These inlets and gratings being situated at the sides of the carriage-way, while the sewer is beneath the middle of it, they communicate by means of transverse drains or passages, which should be formed with sufficient declivity to prevent any accumulation of surface-water or road-sweepings beneath the gratings. The narrower the interstices between the bars of the gratings are, the better. Very small spaces will suffice to admit the water with great rapidity, and also the mud which is formed upon the surface of the streets, and the narrow spaces are useful in preventing the admission of these matters during heavy showers with a force which might endanger the safety of the sewers

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SECTION V.

Conveyance of Water.—Piping, Aqueducts, Reservoirs.—Pumping Apparatus, Steam Draining and Pumping, &c.

379. For the conveyance of water from upper surfaces and sources to towns, open channels, or aqueducts, sometimes afford cheaper means than the laying of piping beneath the surface of the ground. In supplying water from these sources to some of the towns in Scotland, Mr. Thom has had occasion to construct several miles of aqueducts and in preference to adopting direct lines, which are commonly obtained at great cost in the necessary aqueduct bridges for crossing valleys and other expensive works for meeting the difficulties presented by the natural ruggedness of the country, Mr. Thom designs his aqueducts by winding along the slopes, however circuitous the course *thus involved,* and descending only with such a fall as will

allow the water to flow with a gentle current. Aqueducts thus formed are simply artificial rivers, and the entire expense is limited to that of constructing suitable banks and bed for the channel. An aqueduct thus constructed at Greenock, passes through very rugged ground, and has cost not more than 400*l.* per mile. The New River, by which a large section of London is supplied with water from the springs of Chadwell and Amwell, with an additional supply out of the river Lea, near Chadwell, in Hertfordshire, is a fine example of an aqueduct of this kind. This channel, the enterprise of Sir Hugh Middleton, was commenced in 1609, and completed in 1613. The direct length between its extremities is about 20 miles, but its actual length is 39 miles. The average annual quantity supplied by this aqueduct is 614,087,768 cubic feet. Deducting from this the larger consumers and street-watering, together about 33,529,400 cubic feet, the remaining 580,558,368 cubic feet per annum are equal to about 46½ cubic feet per tenement, supplied each alternate day. The reservoirs, in which this supply is stored, are equal to contain the quantity consumed in seven days, or 11,774,000 cubic feet.

380. The city of New York is partially supplied with water from the Croton river by an aqueduct 40 miles in length. The receiving reservoir of these works contains 150,000,000 gallons, and the distributing reservoir 21,000,000 gallons. The supply is effected without either pumps or water-wheels. An interesting work of this kind, a suspension aqueduct, has been constructed for a canal over the Alleghany river at Pittsburgh. This aqueduct consists of seven spans of 160 ft. each, from centre to centre of pier. On the piers are pyramids rising 5 ft. above the level of the side walk and towing-path, and measuring 3 ft. by 5 ft. on the top, and 4 ft. by 6 ft. 6 in. at the base. The two wire cables which support the structure are placed one on each side. Each is 7 in. diameter, perfectly solid and compact and constructed in one piece from shore to

shore, 1175 ft. long, of 1900 wires of $\frac{1}{8}$ in. thickness. Each wire is varnished separately, and the whole cable has a close, compact, and continuous wrapping of annealed wire laid on by machinery. Transverse beams of timber, 27 ft. long, and 16 × 6 in., are placed in pairs at 4 ft. apart. Each pair of these beams is supported on each side of the aqueduct with a double stirrup of $1\frac{1}{8}$ in. round iron, mounted on a small saddle of cast iron, which rests on the cable. Into these beams, wooden posts 7 × 7 in. at top, and 7 × by 14 in. at bottom, are mortised. These posts are the side supports of the water-trunk, which is of wood, 1140 ft. in length, 14 ft. wide at bottom, and $16\frac{1}{2}$ ft. wide at top, and $8\frac{1}{2}$ ft. deep. The sides and bottom are composed of a double course of $2\frac{1}{2}$ in. white pine, placed so that each course crosses the other diagonally at a right angle. The extremities of the cables do not extend below the ground, but are connected with anchor-chains which, in curved lines, pass through the masonry of the abutments. The bars of these chains average $1\frac{1}{2}$ × 4 in., and from 4 to 12 ft. in length. They are formed of boiler scrap iron, and forged in single pieces without welds The extreme links are anchored to cast-iron plates 6 ft. square. The total length of each cable and its chains is 1283 ft., and the weight of both cables 110 tons. The weight of water in each span (4 ft. deep in the trough) is 295 tons. The total solid section of anchor chains is 72 superficial inches. Deflection of chains, 14 ft. 6 in Elevation of pyramids above piers, 16 ft. 6 in. The tension of each wire is 206 lbs., while its ultimate strength will be 1100 lbs.

381. Cast-iron pipes are now universally employed for the conveyance of water. They are formed with socket ends, so that all necessary motion is permitted according to the expansion and contraction of the metal, caused by variations of temperature. Until the commencement of the present century all the water supplied by companies to *London* was conveyed in pipes bored out of elm, and at

that time the New River Company had 400 miles of these wooden pipes in use. The general use of water-closets among the higher class of tenants, about the year 1809, led to the projection of new companies, who undertook to meet the growing want of water-supply at high service, by the use of steam power and iron pipes, a duty for which the old wooden pipes were inadequate. The bore of the wooden mains was from 6 to 7 in., and of the service pipes 3 in. The principal iron mains now vary from 12 to 30 in. in diameter; the sub-mains are 6 and 7 in., and the service pipes usually 4 in. The interior of the cast-iron pipes used for conveying water should be coated with a preparation of lime-water, to prevent corrosion and the consequent injurious effect upon the quality and flavour of the water.

382. Several methods have been adopted for forming the joints of iron water-pipes. Originally they were formed with flanges screwed together, but these were rapidly destroyed by the variations in the total length of piping produced by changes in temperature. Socket joints were then introduced, the joining parts being so formed that an annular space is left within the socket, and outside the entering pipe, for a ring of solder to be poured in, for the purpose of making the joint water-tight. An improvement has been effected in this kind of joint, by making the parts to fit each other, and turning them accurately to a conical form so that a water-tight joint is produced without any stuffing or packing of any kind, a little whiting and tallow only being used to assist the close adhesion of the parts. This kind of joint is so perfect that it has been adopted in forming the joints of a steam-engine suction pipe, 30 in. in diameter, with perfect success. Wooden plugs of suitable taper form have also been successfully and economically applied for forming the socket joints of water-pipes prepared with an annular space, in which they are driven.

383 The weights of cast-iron pipes, as applied for

water-supply, are as follows, according to the size or diameter of the bore.

In.			Cwt.	qrs.	lbs.	
3	diameter of bore	. . . . .	0	3	14	Weight of each pipe measuring 9 ft. in length.
4	" "	. . . . .	1	0	14	
5	" "	. . . . .	1	3	0	
6	" "	. . . . .	2	2	0	
7	" "	. . . . .	3	0	0	
8	" "	. . . . .	4	0	0	
9	" "	. . . . .	4	2	0	
12	" "	. . . . .	6	0	0	
20	" "	. . . . .	12	2	0	
36	" "	. . . . .	34	0	0	

384. In determining the proper size for pipes, according to the quantity to be conveyed, the following formula has been employed—

$$\frac{1}{15}\sqrt[5]{\frac{q^2\,l}{h}} = d,$$

in which q represents the number of gallons to be delivered per hour, l the length of the pipe in yards, h the head in feet, and d the diameter of the pipe in inches. In applying this formula, Mr. Hawksley, Engineer to the Trent Water-Works Company, calculates that for supplying a street of 600 yards in length, the total length should be divided into three spaces of 200 yards each, and the quantity allowed for each of these spaces should be respectively as follows:—

		Gallons per diem.
Final 200 yards	. . . .	13,000
Middle 200 yards,	11,000 + 13,000 =	24,000
First 200 yards,	8,000 + 24,000 =	32,000

The calculation also assumes that the delivery of these entire quantities will take place in four hours, and that the whole of the water taken off from each length has to be passed to the end of that length. The delivery of these quantities respectively will require, according to the formula *quoted*, pipes of the following sizes:—

	Inches.
For the first 200 yards	5·2 diameter.
„ middle 200 yards	4·5 „
„ final 200 yards	3·6 „

Adding about half an inch to each of these for possible contraction by corrosion, the practical diameters become 6 in., 5 in., and 4 in. respectively. The difference in the size of pipes needed for the intermittent and the constant supply systems is exhibited in the following comparative statement:—

	Periodical Supply.	Constant Supply.
Mains	20 in. diameter	12 in. diameter.
„	7 „	5 „
„	6 „	4 „
Service pipes	3 „	2 „

385. Of the cost of raising water with pumps worked by steam-engines exaggerated conceptions are frequently formed, and it is therefore desirable to collect the best evidence on this subject. from which it appears that this cost is really an insignificant item, when the expense of the power is fairly compared with the quantity of water raised, as appears from the table of results (page 143), as stated by Mr. Wicksteed :—In all these cases the coals are taken at 12*s*. per ton, and all charges for working the engine, coals, labour, and stores, are included. but no charge is allowed for interest upon outlay, or repairs of machinery and buildings. To raise 160,000,000 of gallons 100 ft. high would cost according to the

1st statement	£362
2nd „	238
3rd „	222
4th „	100

386. Of the performance of Taylor s pumping engine, in use at the United Mines, the late Mr. Farey made the following computation :—The average duty performed by this engine during the years 1841 and 1842 was equal to the

raising of 95¾ millions pounds weight of water, 1 foot high, by the combustion of 1 bushel of coal. Each bushel of coal weighs about 94 lbs., therefore each lb. of coal consumed by Taylor's engine raises 1,000,000 lbs. of water 1 ft. high. The unit of horse-power adopted by Mr. Watt, viz. a force equal to 33,000 lbs., acting through a space of 1 ft. per minute, is found to be half as much more as the average performance of a good draught horse working 8 hours a day and 6 days a week. A steam engine which raises 94,000,000 per bushel (as Taylor's engine does) consumes only 1·98 lbs. of coal per hour for each horse power which it exerts independently of overcoming its own friction, and that of the pumps That is, when it exerts a power equal to that of 100 horses, it consumes only 198 lbs. of coal per hour.

387. Mr. Hawksley has furnished a compendious statement of his experience in raising and conveyance of water for the town of Nottingham, to this effect:—"The cost of transmitting water to a distance of 5 miles, and to a height of 200 ft., including wear and tear of pumping machinery, fuel. labour, interest of capital invested in pipes, reservoirs, engines, &c., amounts to about 2½*d.* per ton." The same gentleman calculates the resistance from friction in conveying water in pipes according to the formula

$$p = \frac{q^3 l}{140 d^5}$$

in which p represents the horse-power necessary to overcome the friction, l the length of the pipe in inches, q the quantity of water to be delivered in one second in gallons, and d the diameter of the pipe in inches. For the transmission of 500 gallons of water per second, two mains, each of 60 in. diameter, would be required, and the resistance arising from friction in these mains, 25 miles long, would, according to this formula, require about 450-horse power. The power required to *raise* this quantity to a reservoir at a height of 220 ft. would amount to that of 2000 *horses nominally.* The total power required to raise and

transmit a distance of 25 miles, through pipes, 500 gallons of water per second would thus equal that of 2450 horses. These figures are sufficient to show that the cost of raising and transmitting water by steam power is so small in proportion to the quantity of water thus placed at our command, that a pure but distant source may generally be economically applied in preference to supplying an inferior quality of water from more proximate sources

Description of Engines.	Quantity of Water Raised per Diem.	Height to which the Water is Raised.	Cost of Raising 1000 Gallons 100 Feet High.	No. of Gallons Raised 100 Feet High for One Penny.
	Gallons.	Feet.	d.	
1. A single pumping engine, by Boulton and Watt, in 1809, working 10½ hours per diem, 6 days per week, mean power 29½ horses. (Average of 2 years' working.)	612,360	100	·543	22,099
2. Two single pumping engines, by Boulton and Watt, in 1809, working 24 hours per diem, 7 days per week, mean power of each engine 30½ horses. (Average of 10 years' working.)	2,922,480	90	·358	33,519
3. Two single pumping engines, by Boulton and Watt, one in 1816, and one in 1828, working 12 hours per diem, 7 days per week, mean power of each engine 76 horses. (Average of 10 years' working.)	3,601,116	100	·333	36,036
4. One single pumping engine, by Harvey and Co., upon the expansive principle, in 1837, working 24 hours per diem, 7 days per week, mean power 95⅛ horses. (Average of 4 years' working.)	4,107,816	110	·150	80,000

. DIVISION III.

DRAINAGE OF BUILDINGS.

SECTION I.

Classification of Buildings.

388. THE principal classes of buildings, as subjects for water-supply and drainage, are—1, Dwellings; 2, Manufactories; and 3, Public Buildings. Each of these admits of several subdivisions, which should be briefly enumerated, in order to indicate the extent to which they are recipients of pure water and contributors of refuse matters to the sum total of town sewage

389. Dwellings are to be sub-classified according to the superficial area which they occupy, and the average number of residents whom they accommodate, and the arrangements to be provided for the joint purposes of supplying water and discharging sewage are required to be proportional to these two data combined. Upon the extent of area the quantity of rain water will depend, and this has to be entered in the account in two ways, first, as affording an integral portion of the supply, and secondly, as contributing to the sum of the sewage. The principal datum will be the number of persons for whom water is required in each dwelling, and each of whom will yield an average share of the refuse to be removed. The calculations of Water Companies are usually based upon the rental paid for each house as an index to the consumption of water within it, and in this way they recognise an almost infinite number of classes. It is clear, however, that the mere rental furnishes no exact criterion of the number of occupants of a house. Nor would the number of rooms in a dwelling

show this with much more accuracy. On the contrary, it is well known that houses of small rental and comparatively few apartments are frequently receptacles of a greater number of human beings than the more costly and capacious habitations of the wealthy classes. Nevertheless, *it is a fact*, that, with the present habits of the poorer sections of the population, the rental is generally in approximate proportion to the quantity of water consumed,—a fact to be accounted for only upon the recognised and deplorable principle that poverty and uncleanliness are mutual exponents and companions in the social condition of civilised beings.

390. We have estimated (283) 20 gallons as the average daily quantity for each inhabitant of a town, and have supposed this quantity to be sufficient to allow also for an ordinary proportion of manufacturing operations, for the supply of public buildings, and for the extinction of fires (284). This estimate is founded upon the experience had in several towns in which the supply is considered adequate. Reserving the details of the appropriation of this quantity for the next section, we now refer to this general estimate as the datum upon which the proper supply of water to dwelling-houses should be provided, and as being at least approximately correct, if the service be constant, and proper inducements be offered to all classes to cultivate habits of cleanliness. We would, therefore, subdivide the First Class of Buildings or Dwellings according to the average number of occupants of each, and provide the means of water-supply and drainage accordingly.

391. The Second Class of Buildings, or Manufactories, including all consumers beyond households, admits of a subdivision according to the operations carried on. Chemical works, including those for dyeing, calico-printing, &c., rank high as consumers of water. Factories for the making of paper, distilleries, breweries, bakehouses, malting-rooms, slaughter-houses, stables, &c., also consume large quantities. Steam-engines are among the wholesale

consumers. The charges made by the Nottingham Trent Water-Works Company are worth quoting in reference to the consumption of water, as their supply is constant, and provides for high-service, the two essential conditions of a complete water-supply. The charges for house service (according to rental, varying from 5*l.* to 100*l.*) are from 5*s.* to 60*s.* annually, being 10*s.* for 10*l.* rental; 20*s.* for 23*l.* or 24*l.* rental; 30*s.* for 39*l.* or 40*l.* rental; 42*s.* for 60*l.* rental; 50*s.* for a rental from 71*l.* to 75*l.*; and 60*s.* for 100*l.* rental. The incidental charges are as follow:—

		s.	*d.*
Stable and one horse		4	0
Stable and more than one horse, for each horse		2	6
Cows, each		1	6
Warehouses—upwards from		5	0
Offices		5	0
Gardens		2	6
Private baths in dwelling-houses		10	0
Slaughter-houses		5	0
Water-closets in private houses		10	0
Water-closets in warehouses, &c.		20	0
Victuallers' brewhouses, two brewings per week		20	0
Ditto ditto, less than twice per week		16	0
Pipe for watering street in front of private house		7	0
Boilers of high-pressure steam-engines, working 10 hours per day, per horse power		9	0
Lace-dressing rooms, per yard in length, single frames		0	9
Ditto ditto, double frames		1	0
Bakehouses	5*s.* to	8	0
Malt-rooms, per quarter of malt contained in steeping cistern		2	6
Water consumed in erection of new buildings, per yard superficial on plan of each story		0	1
Water consumed in erection of fence walls, per yard superficial		0	0½
Mill-hands, for drinking and washing only, per individual employed		0	3
Workhouses, including baths and washing rooms, per individual on the average of the whole year		0	8

The supplies to dyers, &c., are estimated and charged for according to the size of the service pipes, by the following scale:—

Diameter of Pipe.	Estimated Supply.	Estimated Charge.		
Inches.	Gallons.	£	s.	d.
$\frac{1}{2}$	50,000	1	10	0
$\frac{5}{8}$	100,000	2	12	0
$\frac{3}{4}$	200,000	4	12	0
$\frac{7}{8}$	300,000	6	10	0
1	400,000	8	6	0
$1\frac{1}{8}$	500,000	10	0	0
$1\frac{1}{4}$	600,000	11	12	0
1 and 1 in.	700,000	13	2	0
$1\frac{1}{8}$ and 1 „	800,000	14	10	0
$1\frac{1}{8}$ and $1\frac{1}{8}$ „	900,000	15	16	0
$1\frac{1}{4}$ and 1 „	1,000,000	17	0	0
$1\frac{1}{4}$ and $1\frac{1}{8}$ „	2,000,000	32	0	0
$1\frac{1}{4}$ and $1\frac{1}{4}$ „	3,000,000	45	0	0

The waste water from condensing steam-engines of 500-horse power in the aggregate will amount to at least 1500 gallons per minute, or 3 gallons per minute per horse power.

392. Public buildings requiring constant service are to be divided according to the number of residents or persons to be supplied. Thus, union workhouses, prisons, lunatic asylums, &c., are to be provided at the minimum rate of 20 gallons per diem for each occupant. Baths and wash-houses require quantities in proportion to the maximum number of bathers and washers. Churches, theatres, and other places of public congregation are to be supplied for cleansing purposes according to the cubic contents of each building. In the baths, it may be estimated that a bulk of water measuring 6 ft. in length by $1\frac{1}{2}$ ft. in width, and 1 ft. in depth will suffice for the ablution of each person. This quantity of water will equal 9 cubic ft., or about 54 gallons. The cost of supplying 1000 gallons by the Nottingham Trent Water-Works Company is, as we have seen (paragraph 319) 2·88*d.*, or nearly 3*d.*, and, as this quantity will be adequate to supply about 19 baths, the expense of water

per bath will be something less than one-sixth of a penny. The expense of fuel for heating 100 hogsheads of water—sufficient for 100 of these baths—from a medium temperature of 52° to 98°, including the replacing of heat lost by radiation, evaporation, and conduction, may be taken at about 540 lbs. of Newcastle coal, which at London prices may be averaged to cost 6*s.* The cost of heating each bath will thus amount to about ·75*d.*, and including the water, ·916*d.*, or less than 1*d.* If as much more be added for attendance, and a similar amount for interest on capital in building, and for incidentals, it appears that a hot bath may be well afforded at a charge of 3*d.*

SECTION II.

Supply of Water Levels.—Constant Service.—Quantity required.—Cisterns.—Reservoirs.—Filters.—Valves and Apparatus.—Piping, &c., &c.

393. The relative levels at which water is required to be supplied to buildings in a town will necessarily govern the height to which the main quantity must first be raised. But, practically, as the entire arrangements of the supply should be devised to command delivery at and above the most elevated of the buildings, the heights at which the delivery actually occurs will be found to affect only the current cost of raising, or the duty to be exacted from the power employed. And if this power be derived from steam-engines, its cost will appear to be insignificant in comparison to the space through which the water is raised. The expense of raising 1000 gallons to an average height of 80 ft. is found by the Trent Company to be, excluding interest on capital, less than 1½*d.*, and the cost, according to Mr. Wicksteed's Table of Results (page 143), of raising 1000 gallons to a height of 100 ft. with a single pumping engine on the expansive principle, excluding interest on capital and repairs of machinery, is less than one-sixth of 1*d.*, or 15*d* Al

though the first cost of engines and pumping machinery of this class is very heavy, it will be a liberal allowance to balance this with the remaining ·85d., and we shall then have an average current cost of 1d. for raising 1000 gallons to an elevation of 100 feet. From this it will be readily inferred how small a difference will arise from diminishing or increasing this height to the extent of 20, 50, or 100 ft.

394. The necessity for constant service, great as it is in all buildings, is still more imperative in supplying those of which the demand is of a variable character. In certain seasons, when the occasion for repeated bathing of persons and cleansing of apartments is greatest, these duties require a much larger quantity of water than will suffice at other periods, and this demand of course increases in the same ratio with the number of persons and apartments to be supplied. Thus workhouses, prisons, and all public asylums vary considerably from time to time in the quantity of water required, and all methods of supply, short of constant service, and all provision for storage, fail in one way or another in securing the constant and unlimited command of fresh and pure water. Thus, house-tanks, cisterns, and reservoirs, however capacious and well designed, serve to receive only limited quantities; and if these be ample for all purposes, it follows that if the consumption be lessened the greater quantity of water will remain in a stagnant condition, to be added to but not replaced by the next delivery from the main. The lower body of water in the cistern will thus remain slightly changed, and stirred up only, and in this way a lower bed of impure water, surcharged and rendered heavy with deposited matters, gradually accumulates, suffering a slow diminution by the proportion of impurity which it imparts to each portion drawn off for immediate use. *Pure* or *fresh water* is, by this arrangement, put altogether out of the question.

395. In large public asylums, properly constructed, arrangements would be made for supplying a bath at least

once a week for every inmate. For this purpose an institution having 1000 residents would require weekly 54,000 gallons, or about 6000 cubic ft. of water. And if the supply be derived by a daily delivery, and the bathing be divided equally over 6 days in the week, a tank to hold the quantity for bathing only must have a capacity equal to 1000 cubic feet, or of the minimum dimensions of 20 ft. in length by 10 ft. in width, and 5 ft. in depth. The other purposes of cleansing would require (allowing 20 gallons per diem for each individual) 66,000 gallons weekly, or 11,000 gallons daily, and a tank to be daily emptied and refilled of the capacity of about 2000 ft., or measuring say 20 ft. in width and length, and 5 ft. in depth. For contingencies, provision should be made for about half this quantity in addition, and thus the entire capacity of the tanks should equal 4000 cubic ft., or dimensions of 80 ft. in length by 10 in width and 5 in depth. And if the consumption one day be reduced one-fourth, and the tanks be not emptied before the fresh delivery, which it is practically impossible to effect,—this quantity of stale water will remain in the lower part of the tanks, and each day's reduced consumption will tend to increase the impurity of the water, unless duplicate tanks be provided, and a large amount of water be wasted in their periodical cleansing.

396. In cases where the constant service of water cannot be obtained, and it consequently becomes necessary to provide cisterns for buildings, they should be so constructed and furnished as to combine the operation of filtering with the purpose of storing the water. For this purpose the best form of cistern will be that of which the bed inclines downwards, so that the discharge pipe may be inserted at the lowest point, and the water always drawn from that part of the cistern. The material used being commonly slate, the bottom may still be formed in a single slab for house cisterns (so as to avoid extra joints), declining in both directions. The filtering media, consisting of beds of sand and gravel of different degrees of fineness (as described in

Part I., p. 64), will be arranged in horizontal layers, excepting the lower one, which will lie in the bottom of the cistern, and be dressed to a level on its upper surface. The head of the discharge pipe should be protected with a fine wire-gauze cap, to prevent the gravel washing into the pipe. Below this pipe another cistern for the filtered water should be provided of proportionate capacity, and if the process be too tedious to admit of the filtration of all the water used, that for inferior purposes may be drawn from a pipe entering the cistern just above the filtering beds.

397. The superior quality of rain water in respect to its softness, as compared with water from all other sources, renders it exceedingly desirable, in an economical view, that all the supply derivable from this source should be carefully collected and preserved. In towns this water is commonly wasted, or at least allowed to subserve only the inferior purpose of assisting the flow of the drainage. Yet the quantity which might, by efficient arrangements, be commanded of this superior water is by no means insignificant. The roof of a house of the average dimensions of 20 ft. square, presenting a plane surface of 400 square ft., receives at least 800 cubic ft. of rain water annually, or about 4800 gallons. If well-constructed and capacious gutters are provided, this quantity may be collected with little loss from evaporation, and will form a reserve stock for such special household purposes as it is peculiarly adapted for This quantity should be immediately received in a filtering tank, and the best available method be adopted of purifying it from the carbonaceous matters with which it becomes saturated in passing through a smoky atmosphere and flowing over roof-surfaces covered with a deposit of similar impurity. An economical and well-devised apparatus for effecting this purpose, and applicable to private and public buildings of all classes, is a desideratum yet wanting in the economical supply of water

398. All valves and other apparatus for regulating the admission and use of water in buildings are required to be

constructed in the simplest and most efficient and durable manner. Complicated contrivances are utterly inadmissible to be entrusted to the ordinary carelessness and inattention with which these things are treated in separate households. Apparatus of costly construction will never receive the sanction of landlords, nor will temporary tenants incur the charge of expensive repairs, or devote regular attention to keep ball-cocks and similar appendages in working order. And in proportion as the rental of houses is less, these difficulties are increased. Landlords become more parsimonious, and tenants less interested and more neglectful In this point of view the advantages of constant and high service are rendered more conspicuous than in its application to tenements of a superior class in which a higher rental enables the landlord to be liberal in the construction and appliances of the building, and the tenant shares his disposition to preserve their proper action in order to secure his own comfort and convenience.

399. If the rain-water be not collected for household cleansing purposes, it should at least be made as efficient as possible for scouring the house-drains. An apparatus for this purpose has been suggested by Mr. W. D. Guthrie, a gentleman who has paid much attention to the subject of town sewerage, and was one of the early advocates for the use of small tubes in substitution for the larger drains, constructed of brickwork, which were formerly prescribed by Commissioners of Sewers as the only form of channels which should be permitted access to their subterranean and gigantic sewers or extended cesspools. Mr. Guthrie proposed that the rain-water from the roof be conducted into a cistern, the lower part of which should be formed like an inverted cone, and fitted with a conical valve at the head of a pipe, discharging into the house-drain. This conical valve is to be attached to a vertical chain above it, and connected with the short end of a lever to the other arm of which a cord or chain is fixed, and by which the valve may be occasionally raised from its seat, and the water dis-

charged from the cistern into the drain-pipe with a force proportional to the quantity in the cistern. From the upper part of the cistern a waste pipe is to descend externally and communicate with the drain pipe below the valve, so as to prevent the cistern overflowing, in case the water accumulates faster than it is discharged; the lower end of the waste-pipe being trapped, to prevent the effluvium in the drain-pipe passing into the cistern.

400. One of the most important of the occasional services for which a supply of water is required for application to buildings is, the extinction of accidental fires. For extensive buildings, such as warehouses, factories, and workrooms, tanks have been suggested, and, in some cases adopted, in which a considerable quantity may be constantly stored and ready for instant application for this purpose. This arrangement is, however, scarcely applicable for private buildings, and, where it is employed, the quantity commanded is of course limited, and can never be safely trusted to as affording an adequate supply for extinguishing the fire. In this application of water, again, the system of constant service offers great advantages. Thus, if the mains are kept always filled, an adequate supply is at all times at hand in every direction, and the grievous losses and dangers incurred by delay in obtaining water on these occasions are avoided.

401. The combination of high service with constant service in the supply of water also affords the means of instantly applying jets of water upon the fire until the fire or pumping-engines arrive. These jets are thus available as substitutes for the engines, and the experiments made to ascertain the height to which a jet of water will rise from the main and service-pipes under a fixed pressure, have shown considerable facility in applying jets for this purpose and a corresponding efficiency in their action. The practical limitation to this mode of delivery appears to arise from the extent of supply required, the economy of the use of jets depending upon the amount of pressure that can be

obtained, and the small number of jets which will suffice for the extinction of the fire. The available power in this case is found to decrease in proportion to the extent to which it is employed, and the loss by friction in the leather hose reduces the delivery, and, consequently, the height or force of the jet, 2½ per cent. for every 40 lineal feet of hose through which the water passes. The importance of the results of the experiments with jets here referred to will justify a brief account of them in this place. They were tried on the 31st of January, 1844, upon jets supplied from the mains and services belonging to the Southwark Water-Company, under a fixed pressure of 120 ft.

The first experiment was made over an extent of 800 yards of 7 in. main, which were connected with 500 yards of 9 in., this length being joined to 200 yards of 12 in., continued by 550 yards of 15-inch main to the great main leading from the Company's works at Battersea, the total distance from the works to the experiment being 5500 yards. The heights to which the water was thrown from 2½-inch stand pipes, with 40 ft. of hose and a ⅞-inch jet, were as follows:—

With 1	stand pipe	the water rose	50	ft.
„ 2	„	„	45	„
„ 3	„	„	40	„
„ 4	„	„	35	„
„ 5	„	„	30	„
„ 6	„	„	27	„

When all the fire plugs on the main were closed, except the first and one 2½-inch stand pipe, and 160 ft. of hose with a ⅞-inch jet applied, the water rose to a height of 40 ft.

The quantity of water delivered from the same (7 in.) main through one stand pipe, and different lengths of hose, was as follows:—

With 40 ft. of hose	96 gallons	in	59	seconds.
„ 80 „	112	„	65	„
„ 160 „	116	„	70	„
„ *40 ft. and 2½*-in. jet . .	118	„	27	„

The second experiment was made with a 9-inch main 1400 yards in length, joined to a 15-inch main of 1000 yards in length, and at a distance of 6650 yards from the works. The stand pipes used were $2\frac{1}{2}$ in., the hose 40 ft. long, and the jet $\frac{7}{8}$ inch, as before.

With 1 stand pipe the water rose	60 ft.
„ 2 „ „ . . .	imperceptible difference.
„ 4 „ „	45 ft.
„ 6 „ „	40 ft.

The quantity delivered with the same pipes, length of hose, and size of jet, being

With 1 stand pipe	114 gallons in	64 seconds.
„ 4 „ „	115 „	75 „
„ 6 „ „	112 „	78 „

These experiments, with the two sizes of main-pipe, will indicate the rate at which the quantity is diminished by the friction of the water in smaller pipes, a result confirmed by another experiment made with the addition of 200 yards of 4-inch service and 200 yards of 5-inch pipe to the 9-inch main last referred to. The hose, 40 ft long, and the jets $\frac{7}{8}$ inch, as before.

With $2\frac{1}{2}$-inch stand pipe fixed on the 4-inch service near the 5-inch pipe, the water rose	40 ft.
With 2 do. do. do. . . .	31 ft.
With 1 do. fixed at end of service, or 200 yards from 5-inch pipe, the water rose	34 ft.
With 2 do. do. do. . . .	23 ft.

The quantity delivered in each of these last four cases being respectively as follows:—

112 gallons in	82	seconds
117 „	103	„
112 „	90	„
114 „	118	„

402. In an interesting paper by Mr. James Braidwood, upon the means of applying water for the extinction of fires, read at the Institution of Civil Engineers, it is shown that elevated tanks for a reserve of water for this purpose should be adapted to contain 176 tons of water for each

fire-engine to be employed. This allows for six hours working of an engine having two cylinders of 7 in diameter with a stroke of 8 in., making 40 strokes each per minute, and fitted to throw 141 tons of water in six hours; and, allowing one fourth for waste, the supply required will be as stated, 176 tons. In the case of a large building, provision should be made for working ten engines for this period, and the quantity required will be 1760 tons, or 63,360 cubic feet of water. From this calculation, it will be evident that the dimensions of the tanks would be enormous. If steam engines can be commanded upon the premises to maintain the supply through the mains, the reserve may be reduced to a consumption for two hours, before the expiration of which time it may be expected that the engine could be got to work. This provision is such as may be supposed requisite in dockyards and for large stacks of warehouses, manufactories, &c

403. In the town of Preston, the advantages of the constant and high service have led to the general use of jets and the comparative disuse of engines for the extinction of fires. For this purpose the hose is carried upon a reel, and should be fixed upon a light spring cart, by which the ladders may be also conveyed. The ladders are found to be invaluable appendages for the economical application of the hose without the engines, because the higher the water is carried upward in the hose, that is, the higher the nozzle of the hose is placed, the less is the resistance suffered from the atmosphere. If a jet forced by a pressure of 100 ft. attain a height of 50 ft. when delivered at the ground level, it will still attain an additional height of 20 or 25 ft., when the nozzle is carried up these 50 ft., and the discharge will then take place at a total height of 70 or 75 ft. from the level of the ground And another advantage derived from carrying the hose as high as possible is, that of commanding a more effective discharge of the water than can be obtained when the direction of the jet is conducted on the

ground

404. The piping for the conveyance of water to buildings has to be graduated in capacity according to the quantity required, in the same way that the mains and service-pipes are proportioned to the extent of district and number of buildings they are intended to serve. In supplying towns with drainage water collected in high reservoirs, and thence conveyed by aqueducts to "distributing basins," Mr. Thom adopted a general system of piping, which is so arranged that the water shall always flow within them in one direction, entering at the upper and passing to the lower end At the lower end of each range of piping a cleansing cock is provided, by opening which occasionally any improper accumulation within the pipe may be removed. The pipes are kept constantly full, and laid at a minimum depth of 3 ft. below the surface of the pavement. In some cases, in order to provide very fine cold water to private houses, an iron cistern, to hold about 20 gallons, is sunk 8 or 10 ft below the bottom of the cellar, and supplied with water through a small lead pipe entering it at the top, while the water is drawn off for use through another small pipe, inserted a few inches above the bottom of the cistern. It would appear, however, that the cleansing of cisterns thus situated must be a somewhat troublesome duty, and the means of regular access to a cistern so deeply sunk in the ground must involve a considerable additional expense in construction

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SECTION III.

Varieties of Manufactures and best available Methods of Draining.—Arrangement of Separate and Collective Drains.—Proportion of Area of Drain to Cubic Contents of Dwelling-Houses.—Fall of Drains.—Mode of Construction. Connection with Main or Collateral Sewers.—Means of Access, &c., &c.

405. The several operations carried on within a building devoted to manufacturing purposes should afford the data

upon which to determine the extent of drainage required, but the most ready way of estimating the amount of refuse waters produced, will be reached by assuming this to equal the supply of water rendered to the building. The application of the same rule to domestic buildings or dwellings admits of a more exact calculation as to the capacity of drains required, but these must all alike be governed by the principle, that ample capacity for immediate discharge is to be sought, with due regard to the fact that all passages for the conveyance of liquid or semi-liquid matters are efficient in proportion to the narrowness of the surface over which these matters are required to flow. This is one of the most important results which recent inquiries have established. Sewers and drains were formerly devised with the single object of making them *large enough*, by which it was supposed that their full efficiency was secured. But sluggishness of action is now recognised as the certain consequence of excess of surface equally as of deficiency of declination. A small stream of liquid matter extended over a wide surface, and reduced in depth in proportion to this width, suffers retardation from this circumstance as well as from a want of declivity in the current. Hence a drain which is disproportionally large in comparison to the amount of drainage, becomes an inoperative apparatus, by reason of its undue dimensions; while, if the same amount of drainage is concentrated within a more limited channel, a greater rapidity is produced, and every addition to the contents of the drain aids, by the full force of its gravity, in propelling the entire quantity forward to the point of discharge.

406. There are four conditions which are to be regarded as indispensable in the construction of all drains from all buildings whatsoever. These conditions are—First. That the entire length of drain is to be constructed and maintained with *sufficient declivity* towards the discharge into the sewer to enable the average proportion and quantity of liquid and solid matters committed to it to maintain a *constant and uninterrupted motion*, so that stagnation shall never

occur. Second. That the entire length of drain is to be constructed and maintained in a condition of *complete impermeability*, so that no portion of the matters put into it shall accidentally escape from it. Third. That the head of the drain shall be so efficiently trapped that no gaseous or volatile properties or products can possibly arise from its contents. And, Fourth. That the lower extremity of the drain, or the point of its communication with the sewer, shall be so properly, completely, and durably formed, that no interruption to the flow of the drainage or escape shall there take place, and that no facility shall be offered for the upward progress of the sewage in case the sewer becomes surcharged, and thus tends to produce such an effect.

407. These conditions appear so simple in their statement, that we are disposed to regard them as self-evident necessities, yet an acquaintance with the details of house-drainage as commonly regulated reveals the fact that they have been generally neglected, and that, at the best, the attention they have received has been most unwisely crippled by considerations of cheapness in first cost at the expense of permanent economy and usefulness. Thus we know that house drains are frequently laid with very imperfect fall, not sufficient indeed to propel the matters sent into them except with the aid of gushes of drainage-water; that they are often composed of defective and carelessly-built brickwork with wide joints of sandy mortar; that the head of the drain is commonly untrapped; and that the entire formation is badly designed and defectively executed. We will endeavour to show the arrangements by which the efficient action of the separate drains of houses and other buildings is most likely to be secured

408. The utmost practicable declivity being obtained in the direction of the drain, the efficiency of its action will be further much controlled by the construction adopted and the kind of surface presented to the sewage Any roughness or irregularity in this surface will of course impede the passage of the sewage, and hence arises the neces-

sity for the greatest care in the construction, whatever the material and kind of formation. The first step in the arrangement is, to collect the whole of the drainage to one point—the head of the intended draining apparatus, and the determination of this point requires a due consideration of its relation to the other extremity of the drain at which the discharge into the sewer is to take place. In buildings of great extent this will sometimes involve a good deal of arrangement, and it will, perhaps, become desirable to divide the entire drainage into two or more points of delivery, and conduct it in so many separate drains to the receiving sewer. The length of each drain being thus reduced to a manageable extent, the necessary fall will be more readily commanded, and the efficiency of the system secured.

409. The cost of constructing these minor works, and also the main sewers with which they are connected, is so enormously aggravated by the depth to which they are frequently laid in order to accommodate the basements of buildings, that, for the sake of economy, basement-drainage should either be altogether abandoned or so modified that efficiency shall never be sacrificed in a vain attempt to reconcile the depth of the basement with the position of the sewer. In arranging the drainage of buildings, therefore, the head of the drains should be kept at the minimum depth which will suffice to sink the construction beneath the surface. We have already (353) expressed a conviction, that a thoroughly perfect and economical system of town-drainage must recognise this as a leading principle, and under this conviction we could not be satisfied to admit the difficulty now experienced to be one which should encumber our proceedings so as to involve comparative inefficiency in action and extravagant costliness in construction and repairs.

410. Although it is not within our province in this place to discuss the governmental measures which would be required to authorise and direct such an adjustment of the

details of private drainage as would be necessary to insure their conformity with the principle here advocated, we may be permitted to observe that this direction was, to a considerable extent, assumed and exercised by the old Commission of Sewers, who always declared their authority in prescribing the manner in which private drains should alone be allowed to communicate with the sewers under their jurisdiction. These prescriptions determined the rate of declivity, the relative levels, and the dimensions of the drains, and were enforced by the Commissioners' execution (by their contractors) of that portion of the work which joined with the sewers. The regulations enforced in the City of London (and which, from its independence of the new consolidated commission, are, it is supposed, still enforced) are based upon the following calculation, the stated principle being that "A house cannot be called effectually drained unless the water is taken away from the floor of its lowest story."*

	Ft.	In
Take the least height which a basement story ought to be	7	0
Thickness of a timber flooring on sleepers	0	9
Covering of the drain, say brick flat	0	2½
Height of drain inside	0	9
Current of drain inside the premises, say, 1 *in.* *to* 10 *ft.* for a house 50 ft. deep	0	5
Current outside the house, *i. e.* in the street	0	3
Height of cross-drain above the bottom of main-drain, at least	0	6
	9	10½

This would give (9 ft. 10½ in., or) 10 ft., at the least, depth from the surface of the street to the bottom of a main drain (of 18 in. diameter), and this may be fairly assumed as the least depth at which a private house of the most ordinary description can be effectually drained; but this considers it only as for the drainage of one house.

* It should be borne in mind that this principle becomes impracticable if the lowest story of any house should, at the free will and option of its owner, have another "lower deep" excavated below it, a practice which has been indulged in in the formation of some of the leviathan warehouses in the City.

"When a series of houses, situate in a public way, inhabited by some who will use, and some who will not use, a drain fairly, is to be drained, the question has to be looked at differently.

	Ft.	In.
"For a retail shop, in which the basement story is often used as a warehouse, it cannot be unreasonable to say that the story shall not be less in height than	8	6
Flooring	0	9
Covering of drain	0	2½
Height of drain	1	3
Current inside	0	5
Current outside	0	3
Height above bottom of common sewer	1	6
	12	10½

"As it may be said that a story of less height might do as a wareroom, and, in order to keep the calculation as low as it fairly can be kept, I would assume that the bottom of a common sewer ought not in any part to be less than 12 ft. beneath the surface of the street."*

We have thus quoted these calculations at length, in order that we may be enabled to refer to the details assumed without fear of mistaking the meaning of the official provisions of the Commissioners.

411. By another of the regulations of the Commissioners of the City Sewers, affecting the details of the house drains, we find that since the year 1832 the Commissioners have required that their own tradesmen should be employed to make the whole of the drains up to the front of the buildings, these drains, 15 in. in diameter, being charged at the rate of 5*s.* 6*d.* per lineal foot. And the reason alleged for this regulation was, that the Commissioners found great difficulty in getting individuals to make the drains substantially.

412. The regulations laid down by the Commissioners of

* "Memorandum," laid before the Court of Commissioners of Sewers for *the City of London, &c.*, by their late Surveyor.

Sewers for Westminster for the construction of private drains were as follows:—"That no drains shall be laid into a public sewer, without a special leave for that purpose from the Commissioners. That when such leave shall be obtained, the opening into the sewer shall be made, and the drain built, for a length of 3 ft. from the sewer, according to a plan and section approved by the Commissioners; the whole to be done by a workman to be employed by the Commissioners, and paid by the party requiring the drain, at the prices undermentioned:—For cutting through the springing wall of a sewer, putting in a cemented brick ring, and soundly underpinning the wall round the same, the sum of 10*s.* 6*d.* for each opening. For building a length of 3 ft. 4 in. of 9-in. barrel drain, with proper York keel stone, sound stock bricks and blue lias lime mortar, the sum of 10*s.* 6*d.* for each such length of drain. For the same length of 12-in. barrel drain, 12*s.* 6*d.* The digging to be done at the expense of the party requiring the drain; and notice to be given at the office of the Commissioners when the excavation shall have been made, in order that an officer may attend, and that a workman may be sent to do the required works. As a guide to persons about to build, it is recommended that the private drain of each house or other premises have a current not less than a quarter of an inch to each foot in length, making in the length of 60 ft. a fall of 15 in., to which, adding 13 in. for the height of the drain and brick arch over it, also 8 in. for the depth of ground and paving over the drain at the upper end, and 12 in. from the lower end of the drain to the bottom at the side of the sewer, will make, in the whole, 4 ft. from the bottom at the side of the sewer to the lowest pavement of the building, being the least height necessary to guard the premises from being flooded by water from the sewer."

413. These notices of the regulations which were enacted and enforced by two of the old Commissions of Sewers are sufficient to show that the powers which may now be required for instituting an entire system of house-drainage

under public authority, or that derived from a Commission under the Great Seal, would be no new entrenchment upon private rights. The following order of the Westminster Commission declares its power to deny the right of draining into the public sewers if the depth of the building would require a rate of declivity less than then deemed necessary to insure the proper action of the drain:—" The Commissioners give notice, that whenever the lower floors or pavements of buildings shall have been laid so low as not to admit of their being drained with a proper current, they will not allow any sewers, or drains into sewers, to be made for the service of such buildings."

414. The regulations we have quoted are, we submit, sufficient to show also that the details thus prescribed were not calculated to contribute to a system of efficient house-drainage, being inadequate, in some of the several indispensable conditions before stated (406).

415. Thus for cylindrical drains of 9 in. in diameter, a construction composed of the ordinary rectangular bricks, with mortar joints, is essentially unsuitable and imperfect, being unavoidably permeable to a considerable extent; the irregularities which occur at every joint, moreover, impair most seriously the effectiveness of the declivity which, if only 1 in. in 10 ft., or 1 in 120, as allowed in the City of London, is, even if fully preserved, inadequate for the purpose. The Westminster allowance of a quarter of an inch in each foot, or 1 in 48, is barely sufficient to make the rapid passage of the sewage a matter of certainty. And drains are much more likely to act efficiently if laid with a fall of 1 in 20 or 30. These regulations illustrate the two alternatives to which the present system reduces the practice and the utility of house-drains. In the one division we have an utterly inefficient declivity of 1 in 120, coupled with a *minimum* depth of 12 ft. from the bottom of the common sewer; while, in the other division, the Commissioners, with an arbitrary kind of wisdom, decline to at-*tempt* the task of draining any premises with basements

"laid so low as not to admit of their being drained with a proper current." The "propriety" of the current would, however, be considerably enhanced by still increasing the fall of 1 in 48, which they adopted

416. The common occupation of the basement stories of houses as kitchens and water-closets, has made it appear desirable to depress the drains and sewers, in order to receive the refuse matters below the level of these basements; but as this object involves one or both of the evils we have pointed out, viz. deficient declivity and consequent stagnation in the drains, and a general system of sewers sunk so deeply in the ground that incomparable expense and difficulty are created in construction, access, and repairs, the purpose of basement-draining should be abandoned, and practicable methods sought of delivering the entire drainage immediately beneath the surface of the ground. If, indeed, no practicable methods could be devised of doing this so as to render basement-draining unnecessary, it must of course be admitted as part of the purpose of house-drainage, in order to avoid the sacrifice of the healthiness of human habitations, which we all readily admit as the final object of the art of draining towns and buildings.

417. The selection of the methods to be adopted for this purpose will be dependent mainly upon the internal arrangements of the building and the occupation of its lower apartments. In the first place, *water-closets must in all cases be constructed above ground*, or, at any rate, so nearly above, that the discharge shall take place within a foot or so of the surface. However valuable the ground-floor space of any premises may be, sufficient room may and always should be reserved for this purpose, as this level is the most desirable for the situation of these accommodations. If placed higher, they cannot be so readily aided with the sewage water produced in the domestic offices, unless these occupy a similarly-elevated position; and besides this objection, is that of having an unnecessary length or extent of drains above

the ground. The most desirable arrangement, therefore, is that which collects the entire drainage at or near the ground level, and there at once and immediately delivers it into the subterranean channels. If, however, it is in any case unavoidable that the kitchen and similar domestic offices are situated in the basement of the building, it will be still equally imperative that all the sewage water shall be delivered into the drain at or near the ground level. No sink or other apparatus for discharging refuse water should be retained in the basement, and the extra labour of carrying this water up to the surface level, or head of the drainage, must be incurred as the penalty of this misconstruction or misappropriation of the building.

418. These arrangements, although involving expense in the alteration of some of the existing buildings in towns, are not to be magnified into impracticabilities. As essential parts of a general system conducive to the health of the entire population, they should be commanded and enforced by adequate public authority, and carried into immediate effect without favour or evasion. And in the construction of new buildings, they should be regarded as imperative general orders, sanctioned by the public well-being, and, if necessary, to be obeyed under official superintendence The truth of principles and advantage of modes of action, established by experiment, should command their adoption without opposition, from the prevailing squeamish reluctance to interfere with private arrangements, which, be it remembered, are, if misdirected, really in these matters public nuisances.

419. The keeping of the basement itself of a building dry by draining is not, we submit, to be acknowledged as a proper purpose of a correct general system. Sufficient and sound construction are alone needed to maintain basement stories of any depth in a perfectly dry condition, if all sewage and rain-waters are, as they should be, collected and discharged into the sewers before they reach the basement. The draining of the surrounding subsoil to the

entire depth of the foundation of a building is a want which cannot arise, if the entire structure up to the ground level is *waterproof*, which we contend it should be; the means of effecting this by the materials now at our command, being of economical and certain application

420. Discarding brickwork and all similar constructions of small parts, as unsuitable for obtaining the impermeability and smoothness of internal surface which are especially required in small drains, the current in which is often reduced to a very small quantity of liquid or semi-solid matter, we are led to seek some tubes or pipes, which shall require only annular joining at distant points, and thus admit of the regularity of surface which is so necessary to assist the passage of the drainage. The stone-ware is now offered as a superior material for this purpose, admitting of much greater economy than iron, and being entirely free from the chance of corrosion and permeability. By glazing the interior surface, moreover, tubes of this ware are made peculiarly suitable for adoption in forming drains; and carefully-made socket joints laid in the direction of the current are cheaply executed, if moulded conically and luted with a little cement of best quality.

421. The size of the drain-pipes has to be graduated according to the quantity to be passed through them, limited in the minimum extreme so as to avoid stoppage from the excessive bulk of the sewage matters, and in the maximum extreme so as to obtain all the rapidity of progress of which a small stream of water is capable, retarded by the friction of the surface over which it passes. For moderate-sized houses, say of eight rooms, and holding some five or six persons on an average, a tube of 5 in. in diameter will suffice for the house-drain. The area of the drain may be proportional to the cubic contents of the house, but if so, in diminishing ratio. That is, if a 5-in. pipe will be large enough for an average-sized house, a pipe of double the area of such a pipe will not be required for a house of

double the cubic contents, or holding double the average number of persons. A 6-in. pipe, laid with sufficient fall, will be ample for the most capacious private house. And from 9 to 15 in. will, under a similar condition, be sufficient to serve the average drainage of factories and other large consumers of water.

422. The trapping of the head of the drain, so as to prevent the ascent of smell and impure gas from the drain into the building, is the next indispensable requirement in the draining apparatus. So many contrivances have been applied for this purpose, that we will not attempt to make a selection; and it is beyond our limits to give any general list or detailed description of them. Simplicity of construction and permanence of action are, of course, required, with the least original outlay at which these qualities can be obtained. If only one water-closet is to be provided for, it will be desirable to gather the discharge from it and from the house-sink, &c., into one trap at the head of the drain. If two or more closets are to be served, so many separate traps will sometimes become indispensable. But for every separate inlet to the drain, which is equally an outlet for smell and gas, an efficient trapping apparatus of some kind is required.

423. The lower connection of the house-drain with the public sewer is the last point of importance to which we have to allude. A perfect construction of this portion of the work has always been recognised as an essential feature of good drainage, and the Commissioners have accordingly stipulated that its execution should be entrusted only to their own contractors, and be subject to the inspection and approval of their own officers. The level of the bed of the drain must be kept as high as possible above that of the receiving sewer. If the sewer be also constructed of the glazed stone-ware piping, lengths of it may be introduced at convenient intervals, having outlet sockets for receiving the ends of the house-drains, and those being slightly tapered or conical in form will be readily jointed with a little

of the best blue lias cement or other of equal quality. If the sewer be constructed of brickwork, a good joint will be obtained by introducing a separate socket of stone-ware to receive the horse-drain pipe, and formed with a flange at the other end to surround and cover the opening in the sewer, which can then be made good with a ring of cement carefully applied.

424. Means of access to house-drains are always desirable in arranging the details of the apparatus. And this constitutes another reason against the deeply-sunk drains required to serve the basement story of houses. If the drains be constructed of glazed stone-ware pipes, carefully jointed, and laid in directions as nearly uniform as possible, the process of artificial cleansing and raking (should it ever become necessary) will be much facilitated. If any angular turns are formed in the direction of the drains, it will be worth while to consider the practicability of fitting a movable cover at the angle, by removing which, direct access should be afforded to the two branches of the drain. A long pliant rod with a stiff brush or scraper at the end could then be readily introduced into the drain, and, if necessary, these means of access by trap doors and removable covers should be afforded at intervals throughout each extended length of drain, so that thorough cleansing from the head of the drain to the outlet in the sewer could be performed as frequently as might be found requisite. Under a complete and efficient system of drainage the task of periodically examining the separate drains from the buildings would be ordered and performed with all the regularity and readiness of a necessary duty, and the drains would be maintained in a state of constant instead of intermittent cleanliness. *

* The system of *subways*, recently introduced in some parts of the metropolis, will probably supply facilities for examining the minor drains, as well as the main sewers, to a degree not hitherto practicable. (1865.)

SECTION IV.

Water-closets; Arrangement and Construction.—Adaptation to various circumstances.—Combined Arrangements for Efficient House-Drainage.—Miscellaneous Apparatus and Contrivances.

425. The best position for a water-closet in any building is that in which all the waste water shall be made the best use of in scouring the contents directly through the pan of the closet, and propelling them forward through the private drain into the common sewer. And since the matters discharged into the closet will be, if the house drain is reserved for its proper uses, more solid and less readily conveyed than the other sewage matters, it will, moreover, be desirable to place the closet as near as possible to the point at which the drain discharges into the sewer. The velocity and force of the liquid sewage are increased at the lower or sewer end of the drain, and its effect is thus augmented in scouring away the contributions of the closet. But if this preferable position cannot be commanded for the closet, it must, at any rate, be so situated with regard to the head of the drain and the inlet for the liquid sewage, that these shall be behind or above it. When the closet and the house-sink are near to each other, the water from the latter may be conducted directly into the trap or basin of the closet, and thus secure at once a rapid discharge of its contents and a constant supply of liquid to preserve its action and efficiency.

426. The rudest form of domestic accommodation or open privy over a cesspool is a contrivance which deserves notice only on account of its several imperfections, and which will, it may be hoped, be soon reckoned among the obsolete mistakes of our forefathers. These cesspools are sometimes mere pits or holes excavated in the ground, and the contents of course rapidly permeate the surrounding soil; by which process pits of this kind frequently are *found to drain* themselves, the perviousness of the material

permitting the escape of the sewage, so that little accumulation takes place within the pit itself until the whole neighbourhood becomes fully saturated with the drainage, which will then ooze through and appear upon the surface, or find its way through some defective foundation, and poison the basement of an adjoining building. Constructed cesspools formed with brickwork of substantial quality will prevent this saturation in proportion as their walls are carefully and imperviously built. The matters daily discharged into these depositaries accumulate, and their decomposition is constantly proceeding and engendering gases of the most noisome and pestilential kind. The open privy formed over a pit of this description affords an outlet for the escape of these gases, which are thus regularly supplied to the building above or adjacent to the closet. If a trap or water basin and pan be applied to this privy, so that the pan dips into the trap, the escape of effluvia may be prevented so long as the trap is kept supplied with water. The supply of water for this purpose will, however, considerably augment the bulk of the sewage, and necessitate cleansing much more frequently than otherwise, unless some defect in the joints of the work afford a passage for the liquid matters in the surrounding strata, or a communication be afforded with a drain. In this latter case of combination of a cesspool with a drain, a waste pipe may be laid from the former into the latter, so that the contents of the cesspool shall always be maintained at the same quantity and depth; the trap may then be dispensed with by attaching a vertical pipe to the lower part of the pan, so that this pipe shall dip into the sewage, and being thus constantly kept below its surface, no gas can pass upward through the pipe. The cost of the pan or basin and pipe required for this contrivance, if of stone-ware, will not exceed 13*s.* in addition to that of a common privy, and its advantages in preventing the escape of effluvia are obvious. The simplest and cheapest form of trap and basin is that in which they are formed in one or two pieces of the stone-ware,

and may be purchased at about 7*s*. 6*d*. together. Allowing 5*s*. 6*d*. for the fixing, and also providing and fixing a short length of pipe of the same material to connect with the trap so as to dip into the sewage, this complete trapped apparatus may, at a cost of 13*s*., be added to a common privy over a cesspool, so as to prevent to a great extent the escape of effluvia into the house or adjacent building.

427. The great importance, however, of avoiding all sources of unwholesome and offensive effluvia, and of preserving the foundations of the buildings and the substrata of the soil of a town in a dry and clean condition, creates a severe necessity for relinquishing cesspools, and all *receptacles* for sewage, within or connected with all buildings and places whatsoever, except those to which it is conducted for the purposes of collection and treatment. *The sole purpose of all house apparatus of water-closets, sinks, and drains, and of all public constructions of branch or tributary sewers, and main sewers, should be that of affording a passage for the conveyance of the refuse waters and other matters produced in a town. This conveyance should be immediate, every particle committed to the entire ramification of passages being preserved in ceaseless motion until it arrives at the final collecting place.*

428. Discarding cesspools upon these grounds, we are at the same time led to the principle which should govern the whole of the details of house-draining apparatus, which should be so arranged and combined as to afford the fewest possible inlets for effluvia from the matters committed to the drains, and to make the total of the liquid refuse useful in advancing the current within the drains. The position of the water-closet being determined (425), it becomes desirable to select the most economical and efficient construction for it, and for the apparatus connected with it.

429. We have already (422) stated that the head of the drain, and every inlet to it, requires to be fitted with a *trap to prevent* the escape of effluvia, and this will equally

form an indispensable part of the closet apparatus. The perfect action of the trap will demand a means of supplying water on each use of the closet, and although all possible advantage should be taken of the house-sewage water in promoting the action of the drains, a separate and constantly-commanded source should be provided for this purpose. If the supply of water to the house or building be rendered upon the constant service system, a mere tap will be sufficient to afford the means of discharging a volume of water through the trap of the closet. If the water be supplied upon the intermittent system, a cistern or reservoir of some kind, provided for the house supply, must be made to communicate with the pan of the closet by a pipe with a valve and apparatus for working it. For general use it is especially desirable that economy and simplicity be combined in the whole of the apparatus of the closet. Delicacy of adjustment, requiring a complicated arrangement of parts, and a corresponding costliness of construction and repairs, and carefulness in management, is inadmissible in a design adapted for general adoption; and combinations of levers and cranks, liable to accidental derangement and injury by roughness of treatment, are therefore to be avoided as much as possible. The position of the cistern in relation to the closet will affect, in some degree, the force and efficiency of the volume of water discharged on each occasion; and, if the supply of water to the building be constant, the service-pipe should be so conducted over the closet that the tap can be conveniently placed for admitting the required quantity to the pan. If the supply is obtained from a house-cistern, this must, of course, be placed above the pan, and at such elevation that the water may acquire a sufficient impetus to flow with rapidity.

430. The glazed stone-ware basins or pans, with syphon-traps combined, before referred to (426), are the most economical and effective for general purposes. These are made in several forms: viz. with the pan and trap in one piece, and adapted to communicate either with a vertical or a hori-

zontal drain; with a separate trap, having a screwed socket on the head in which the lower part of the pan is received, being formed with a collar and screwed end; or, as a somewhat more complicated arrangement, consisting of a trap with a flanged head and a separate dip pipe having a projecting flange about its mid-length, and a spreading mouth above, into which the lower part of the pan is fitted with cement. The dip pipe, extending downwards into the trap, below the level at which its contents flow out, is secured to the head of the trap by bolts passing through the holes in the flanges. The reason for making the pan separate from the dip pipe would appear to arise from a difficulty in forming them together with the wide projecting flange so as to give sufficient steadiness to the pan above. This latter form was designed especially for prison use, under circumstances which do not allow of any fixed seat or framing above to which to secure the pan. The previous forms are found to answer all purposes in cases where this kind of support is afforded, and are preferable for their fewer number of parts. The pan in each of these forms of construction is provided with an aperture and inlet at the upper part, having a socket to receive the water-pipe. They are retailed at the price of 7*s.* 6*d.* each, and recommended by the present authorities in drainage matters.

431. The combined arrangements for efficient house-drainage comprise, besides the means of adequate water supply, as explained in section II. of this Division, the water-closets, house-sinks, and drains in which the matters committed to the closets and sinks are conveyed and delivered into the public sewers. And if the rain-water falling on the roof of the building and on the yard or space attached to the house, is not applied to any other purpose, it will have to be conducted into the drain to be discharged with the sewage. These waters being the purest of the contents should be received as near as possible to the head of the drain, and made to traverse its entire length, and *thus exert all* the cleansing action of which they are capable.

The house-sink or place at which the ordinary waste water of the household is discharged should communicate with the drain at a subsequent part of its course, and the closet be so placed that its contents shall traverse a minimum portion of the drain, thus reducing the liability to the escape of effluvia, and deriving the greatest scouring force from the accumulation of the rain and house waters. The drain being formed as a complete and impervious channel receiving the entire sewage and waste waters of the premises, made easy of access and examination, and provided with traps at every opening or inlet for receiving the drainage, may be graduated in size from the one extremity to the other, and, if of considerable length, it may be provided at intervals with self-acting valves or traps to prevent the possible return of any matters, waters, or gases, from the lower towards the upper end.

432. Self-acting valves or traps are constructed of the stone-ware; and the valves being hung at a slight inclination, and well fitted with a rim on the meeting surface, they remain closed against any retrograde movement of the sewage or gases, but are readily opened by a slight force of water in the outward direction of the drain. Sink traps are also formed of this material, with perforated heads or covers, and syphon bends below, which, remaining filled with the drainage water, prevent the escape of any effluvia from the drain into which they give access.

433. Beside the socket drain pipes of glazed stone-ware which we have described, another material, known under the name of "Terro-metallic," has been applied in the production of a superior quality of piping, which is manufactured in cylindrical forms both with socket ends and plain butt ends, and also in a conical form with plain ends, the cones fitting one another so that the joints are similar to conical socket joints, and may be made to fit with a great degree of exactness. The material of these pipes is of the same quality as that used in making fire-bricks, and has an extreme density with a very durable glaze upon the surface.

The prices of these pipes at the Tileries, Tunstall, Staffordshire, where they are manufactured, and in London, are as follows :—

TERRO-METALLIC DRAIN PIPES.

Diameter of Bore.	Plain Jointed Cylindrical Pipes.		Conical Pipes to Fit one another.		Cylindrical Pipes with Socket-Joints.	
	Price per Foot at Tunstall.	Price per Foot in London.	Price per Foot at Tunstall.	Price per Foot in London.	Price per Foot at Tunstall.	Price per Foot in London.
Inches.	*s.* *d.*	*s.* *d.*	*s.* *d.*	*s.* *d.*	*s.* *d.*	*s.* *d.*
2	0 2	0 3	0 $2\frac{3}{8}$	0 $3\frac{1}{2}$	......	......
3	0 $2\frac{5}{8}$	0 4	0 3	0 5	0 $3\frac{3}{4}$	0 $5\frac{1}{2}$
4	0 $3\frac{3}{8}$	0 5	0 $3\frac{5}{8}$	0 6	0 $4\frac{1}{2}$	0 $6\frac{3}{4}$
6	0 4	0 6	0 $4\frac{5}{8}$	0 9	0 6	0 9
9	0 6	0 11	0 8	1 2	0 9	1 3
12	1 2	2 $1\frac{1}{2}$	......	......	1 $4\frac{1}{2}$	2 3
16	2 3	3 9	......	......	2 6	4 0

Curved and Junction pipes in the same material are charged at double the prices of the cylindrical pipes.

434. One of the most valuable improvements recently effected in the practical cleansing of buildings is a portable pumping apparatus, with hose for emptying cesspools. For conveying the sewage, this consists of a close tank mounted upon two or four wheels, according to its size, with a hose fitted to an aperture in it, and an air-pump attached, so that the chamber communicates with the interior of the tank. The hose is provided of such length that it may be laid through the passage, &c. of a house, and dipped into the cesspool, while the other end is attached to the tank at the door, into which the contents of the cesspool are rapidly transferred, without offence or nuisance, by a labourer at the pump. A small pumping apparatus with hose, but without tank, has been extensively applied for removing the contents of the cesspools into the sewers, a second hose being attached to the pump-chamber for this purpose. This apparatus, with hose complete, is furnished at the price of *15l.*, and the economy of its use as compared with the cost

of cleansing cesspools by the old method, effects a saving of 95 per cent. Among the instances reported by the Surveyors to the Metropolitan Commission of Sewers, the following may be quoted:—"The contents of one large cesspool, equal to 24 loads of soil, were pumped out in 3¾ hours, at a cost of 24*s*. Under the old system, three nights would have been occupied in emptying the cesspool and it would have cost at least 24*l*."

435. Among the many contrivances which have been suggested for improving the house-apparatus for regulating the disposal of the water supplied, is a simple form of cistern, introduced by Mr. John Hosmer, which appears well calculated to prevent the waste of water which now frequently results from the inefficiency of the apparatus employed. The amount of this waste may be inferred from the proved fact that, in one district of the metropolis, an average quantity of *twenty-nine* gallons per house is wasted at each delivery from the works, by dribbling over the waste-pipes of the cisterns after they have become filled. Mr. Hosmer's cistern has a partition, dividing it into two spaces, one considerably larger than the other, and containing the supply for domestic use, while the smaller space is intended to contain a reserve for cleansing the drains and sewers. A two-way cock is fitted on the cistern with ball and lever, and one aperture of the cock opens into each of the spaces in the cistern. The large division of the cistern is fitted with a pipe or pipes to deliver the house supply as required, and the small division has a syphon-trapped pipe, leading into the drain and covered by a valve, the vertical rod of which is attached to the lever of the two-way delivery cock. The water from the main first fills the small division, the position of the lever being such that the valve at the lower part remains closed. The water then flows over the partition (which is kept a trifle lower than the sides of the cistern for this purpose) and fills the large division, the rising of the ball in which overcomes the pressure upon the valve in the small division, and lifts it suddenly to such

a height as to permit of a rapid discharge of water through the syphon-trapped pipe into the drain. Similar cisterns thus fixed and fitted, deriving their action simultaneously from the delivery at the main, would, it is supposed, discharge streams of water at one and the same time into the several house-drains connected with them, and thus act with considerable efficiency in scouring these drains and the sewer into which they discharge.

436. Although complexity of parts is to be avoided in water-closets intended for use in the greater number of dwellings, some of the more complete forms of apparatus adapted for self-action, and which necessarily comprise considerable detail of arrangement, are preferable in superior buildings in which close economy of construction is not a first condition, and regular care and attention can be secured for the action of the apparatus employed. In some of these closets, the valve which opens and closes the opening into the water-pipe is attached by a rod to a lever, which, by means of a cord or chain, is connected with the door of the closet, so that the opening of the door opens the valve and thus discharges a quantity of water into the pan. In another form of apparatus, the pressure of the person on the seat produces a similar effect. One of the most improved of these is that patented by Messrs. Bunnett and Co., which will be found fully described and illustrated in the "Civil Engineer and Architect's Journal" for the month of April, 1849. This closet is self-acting and doubly trapped, and designed to secure a supply and force of water which shall always be efficient and uniform without waste. It is, moreover, so contrived, that no soil can remain in the basin after use, and an ample supply of water being secured in the basin so as to form a "water-lute" between that and the syphon-trap, the rising of smell is effectually prevented. The lower part of the pan dips into a water-pan or trap, which is hinged and maintained in a horizontal position by a rolling balance weight. The effect of pressure on the *seat of the closet* is to depress a lever and open a valve in

the supply-box of the cistern, and thus pour a volume of water into the water-pan or trap sufficient to throw it open, and afford a passage for the soil into the lower basin, which terminates in a syphon, and is also trapped with water. When the pressure is removed from the seat, the water-pan or upper trap is immediately brought back to a horizontal position by the rolling weight, and receives sufficient water before the closing of the valve, to fill it, and thus effectually shut off all communication with the lower basin.

GENERAL SUMMARY AND CONCLUSION

437. In the First Part of this Rudimentary Treatise, devoted to the Drainage of Districts and Lands, an attempt is made to exhibit an arranged outline of the facts which have been observed and recorded with reference to the several sources of water for agricultural purposes, and the best means of making these available. The methods of filtering and purifying water for extended purposes in districts comprising towns, are also briefly explained, and the difference pointed out between the mechanical and chemical processes required. In the sections which treat of the drainage of lands, as limited in its purpose to the discharge of superfluous water, the peculiar method to be employed is shown to depend on the united consideration of relative levels of surface and structural formation of soils. The importance of efficient draining of fens and the several works required for this purpose, are illustrated by grand instances in our own country—in the counties of Lincoln and Cambridge—and a brief description is introduced of that celebrated Dutch work by English engineers, the draining of the Lake of Haarlem. The construction of catch-water drains, and the adoption of means for aiding the supply of water to high or upland districts, are also alluded to as among the duties of the drainer. The formation of

soils is described as affording a general knowledge of their character, and aiding in the determination of the best arrangement of drains. Adopting a general classification of soils in regard to their structure, under the three leading characters of porous, retentive, and mixed, an extended notice is devoted to the several arrangements of these soils which are met with, and the modes of proceeding in each case are briefly explained. A description of the several modes of forming drains or artificial subterranean channels through lands is accompanied by practical rules as to their construction, dimensions, arrangement, and cost, and some of the best experience on this subject is quoted. A brief account of the several operations to be carried on, of contour-mapping, and of the tools employed in draining, completes the First Division of the work

438. The Second Division, of which the purport is the Drainage of Towns and Streets, aims at establishing a classification of towns as subjects for water supply and drainage according to the relative levels of the surface, and without that reference to the contiguity of rivers which has been dictated by the mistaken object of converting rivers into general sewers. An illustration of the principle here advocated is taken from the position and superficial character of our own metropolis. The value of sewage matters for agricultural purposes, and the practicability of rendering the distribution and use of these matters innocuous by chemical processes, are also stated upon the highest authority, and the evils of concentrating the sewage of large towns at few points, and misusing the channels for its conveyance, are pointed out and established upon past and extended experience. A brief notice is added of some of the general plans which have been suggested for the drainage of London, and some particulars given of the costly and inoperative works executed in the department of Metropolitan Sewerage. Upon the public supply of water to towns a mass of evidence is collected from past experience in the *metropolis and the* provinces, showing the effect of geologi-

cal structure upon the quality of water, and the cost of supplying, of filtering, and purifying it for the several purposes required. The circumstances affecting the cleansing and draining of roads and streets are also shortly noticed. The proper functions of sewers, their arrangement, dimensions, and construction, are deduced from the data which it is believed should be referred to, and by calculations which our past experience enables us to form. A rule for the correct sectional form of sewers is also given, and recommended for its usefulness and simplicity. The cost of several descriptions of sewers is also cited from the records of experience, the stone-ware pipe sewers described, and the method of cleansing by flushing adverted to, and its effects quoted. The conveyance of water to towns and the several methods adopted, with the cost of pumping by steam-power, are described and stated.

439. The Third Division treats of the Drainage of Buildings as subjects of the entire system which embraces the supply of water as an accessory to the purpose of draining. It is suggested that the classification of dwellings should be determined by the number of persons to be served rather than the rental paid for each house, and that larger buildings, in which human beings are congregated for manufacturing and other purposes, may be provided for according to the cubic space inclosed by them. The arrangement, construction, and dimensions of house-drains are described, and the qualifications of impermeability, secure trapping at the head and all other openings through which effluvia might escape, and proper connection with the receiving sewer at the lower end, are insisted upon as indispensable to perfect and efficient construction. And in the concluding section a general view is taken of the combined arrangements for efficient house-drainage, and the simplest construction recommended for water-closets and similar apparatus designed for general adoption.

APPENDIX No. 1.

STEAM DRAINING-PLOUGH

440. THE following account of Fowler and Fry's new steam draining-plough is quoted from the "Bristol Mercury" of February 11, 1854.

"On Thursday last some experiments of a deeply interesting and important nature, in connection with the question of land-drainage, were made at Catherine Farm, on the estate of P. W. Miles, Esq., at Kingsweston, when Fowler and Fry's new steam draining-plough was for the first time put in operation. The great utility of underground drainage upon clay soils and in marshy districts is now too generally known and appreciated to leave it a matter of debate; but the heavy expense which the adoption of the system of hand-labour entails, especially in neighbourhoods where that labour is scarce and dear, has hitherto stood in the way of its general adoption. It will be obvious that anything which has a tendency to facilitate the operation and diminish its cost, must be, in an eminent degree, beneficial to agriculture, and hence scientific and practical men have been stimulated to bend their efforts in a direction tending to those ends. The drainage of moist lands was first attempted by the simple process of digging, by spade labour, narrow trenches, and laying rude stone drains in the bottom of them. The difficulty of procuring stones and the cost of hauling them were found to stand considerably in the way of that process, and the use of draining-tiles in various forms was by degrees introduced, but without any decided improvement being effected *in the mode of* cutting the drain trenches. An important

revolution in the process was introduced by our fellow-citizen Mr. Fowler, of the firm of Fowler and Fry, agricultural machine manufacturers, of Temple Street, in the invention of his draining-plough, by which manual labour was in a large degree superseded; but a deficiency still remained. The plough had to be worked by horse-power, four horses being employed by it in turning the windlass by which it was set in motion, and the process, although cheaper and more expeditious than spade-labour, was, nevertheless, in a degree expensive and tardy. The desirability of applying steam power to a plough upon the same principle soon became apparent, and, impressed with the importance of the object, Mr. Fowler directed his attention to it, and now, as the result of a great deal of anxiety and labour, and of no inconsiderable expense, he has perfected a steam draining-plough, which we saw in successful operation on Thursday, and which we have no doubt will speedily take rank among the most useful inventions of the day. A brief description of the machinery may prove interesting.

"The steam-engine, although mounted on wheels, and capable of being transported from point to point, is, when employed, a stationary one, and worked by a horizontal cylinder. It has connected with it two drums, which are loose on the axles. Attached to the larger drum, which draws the plough forward, is a wire rope of beautiful manufacture, the breaking strain of which is 14 tons, the working strain being 5 tons. This drum is worked by two motions off the fly-wheel shaft, which give a leverage of 22 to 1 on the plough, the drum making seven revolutions per minute. To the lesser drum, which is worked off the second shaft, is attached a rope also of wire, but of smaller calibre, which draws the plough back, when it has completed a furrow, to the side of the field from which it started and where it has to begin again. By an ingenious contrivance the drums are formed by the insides of two spur wheels, so that practically the working is effected by

ordinary spur-gearing. The drums can be instantly thrown out of gear by clutches moving the pinions on a feather. The larger wire rope, on being wound on to the lrum for the purpose of impelling the plough forward, works round a sheave-wheel or pulley-block anchored to the field at such a point as to draw the plough at right angles to the engine, by which arrangement the necessity of shifting the engine is obviated to so great an extent that almost any field may be drained without once removing it from the position first taken up by it. To the front of the plough is attached a second sheave-wheel, round which the rope is doubled, thereby, also, doubling the power. The coulter of the plough is of iron, an inch in diameter at its widest point, so that the furrow made by it upon the surface of the land is scarcely perceptible and generally disappears after the first storm of rain. It can be worked to a depth of four feet, and indeed deeper, if necessary, and is so made that it can be raised or depressed by a handwheel under the control of the ploughman, and which works gear connected with a rack at the back of the coulter. The boring of the land is effected by means of a cast-iron mole or plug (the size of which is regulated by the size of the tiles to be laid) keyed to the bottom of the coulter, and the most striking feature of the machine is, that as fast as it bores the land it lays in the tile-piping, thus completing the drain as it goes at the rate (when we saw it working) of 35 feet, and probably, under very favourable circumstances, 40 feet per minute. It should be stated, in order to the understanding of what follows, that as the engine winds the large rope on the large drum and draws the plough towards it, it at the same time unwinds the small rope which is attached to the back of the plough from the small drum.

"The mode of operation we will now endeavour to explain, assuming for our illustration a field of 1000 feet square, which has to be drained by drains 10 yards apart *from east to* west. The engine would be fixed at the

middle of the western edge; the plough would be placed on the eastern edge at 10 yards from the southern edge of the ground, and an anchor and sheave-wheel would be rigged exactly opposite to it on the western edge. The large wire-rope would be passed round the sheave-wheel, and thence on to the front of the plough, while the small wire-rope would be connected from the back of the plough with another anchor, &c., rigged 10 yards north of the plough—that is, at the point to which it would have to be drawn back, and from which it would have to commence again. The machinery thus arranged, the pipe-tiles are strung on ropes of fifty yards long (the length being thus limited to economise time and labour in threading), but fitted with ingeniously-contrived joints at either end, so that they can be readily and firmly joined together at any length required. These ropes are made of hemp for the sake of flexibility, while, as a matter of economy and durability, and to decrease friction as much as possible, they are coated with wire. The ropes being threaded and joined, one end is fixed immediately behind the mole, and the machine being set in motion by the steam-engine, the coulter cuts its narrow channel through the land, the mole bores and lifts the subsoil, and the pipes are drawn through the aperture, and closely and neatly put together, forming the drain. The sheave-wheels are then shifted, the plough drawn back by the small rope, and the second and succeeding drains are cut and piped in the same way. The ropes, after the tiles have been laid, are drawn out by horses, which is the only employment of horse-labour required. The plough is attended by a man, whose only duty seems to be to keep it upright where the land is out of level; but we were told by Mr. Fowler that he had perfected some self-acting level guides, which would be shortly attached, and which would enable the plough to adapt itself to any inequalities which might arise, and make it independent of any guide.

"The advantages which Mr. Fowler expects to derive from his inventions are manifold. The first and most

important is, of course, economy. The sum at present charged by contractors, for draining on a large scale, per acre, is from 5*l.* to 6*l.* A considerable tract of land, at present in course of drainage in an adjacent county, is understood to have been taken at 5*l.* 5*s.* or 5*l.* 10*s.* per acre. Mr. Fowler considers that by his machinery land may be drained for from 3*l.* 10*s.* to 4*l.* per acre, yielding a fair remuneration to the contractor. One engine with ten men and two horses will, he calculates, do as much work as 120 men, and, under favourable circumstances, as much work as 150 men would do by the old system. A second advantage anticipated is, the ability to drain in the summer season, when days are long and the weather favourable, a desideratum not now obtainable on account of labour being at that period so fully occupied by other sources of employment. Third, drainage by the machine will be better performed. The drains will be uniform in depth and straighter, and the tiles more closely and firmly laid, while the plough, by lifting the land, causes the water to percolate at once, and thus brings the drain into immediate action. Fourth, no damage is done to the surface of the ground, which, by the old process was often the case. With dry weather the machinery may be erected and field drained one day, and on the next a casual observer would be unable to perceive that any change had taken place. Fifth, the drains when made will be more durable.

"With regard to the capabilities of his invention, Mr. Fowler calculates that with a single engine and plough he shall be able to drain about 30 acres per week. At present the machinery will only be retained in this neighbourhood long enough to complete the drainage of about 40 acres of land on the farm where it is now at work. This will probably be effected by about the end of next week, after which time it will be removed to London, in the neighbourhood of which city it will, we understand, be tried under Government inspection, and, doubtless, will receive

the attention of many scientific and practical gentlemen interested in the advancement of agriculture

"Should the 'STEAM DRAINING-PLOUGH' meet with the approbation of those to whom it is about to be submitted, arrangements will be made for carrying it into operation upon a scale to some extent commensurate with the wants of the kingdom."

Figures 78, 79, 80, and 81, show the plough and capstan apparatus complete, as adapted to be propelled by horse-power. Figs. 78 and 79 are an elevation and plan of the capstan, and figs. 80 and 81 a corresponding elevation and plan of the plough

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[Since the above was written, very considerable advances have been made in the practice of plough-draining by steam-power, as in the application of the same mighty agency to other agricultural labours; but the principles are nearly as above described.]

Fig. 78.

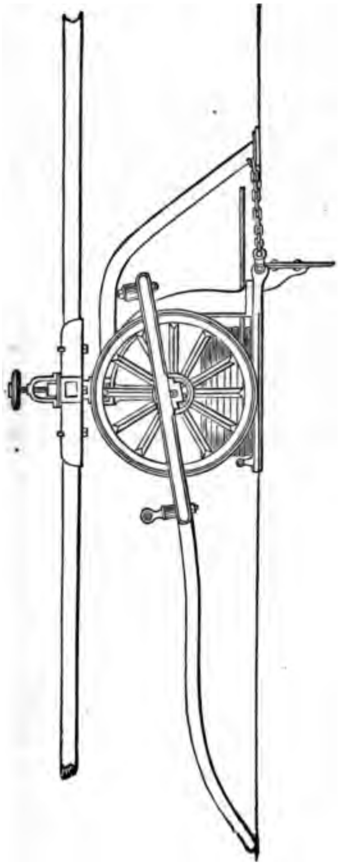


Fig. 79.

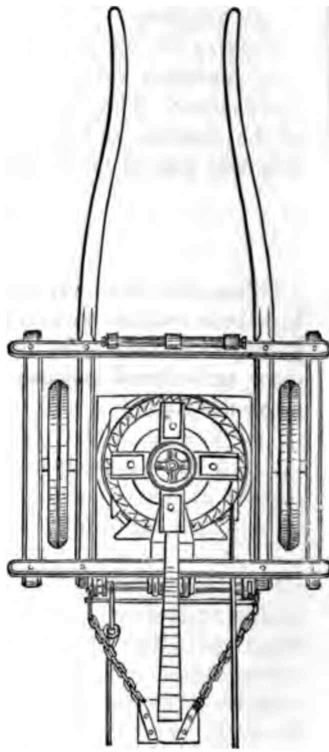


Fig. 80.

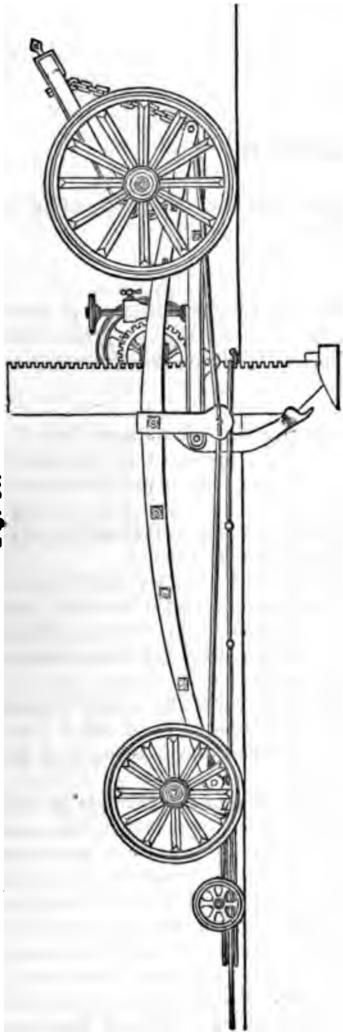


Fig. 81.

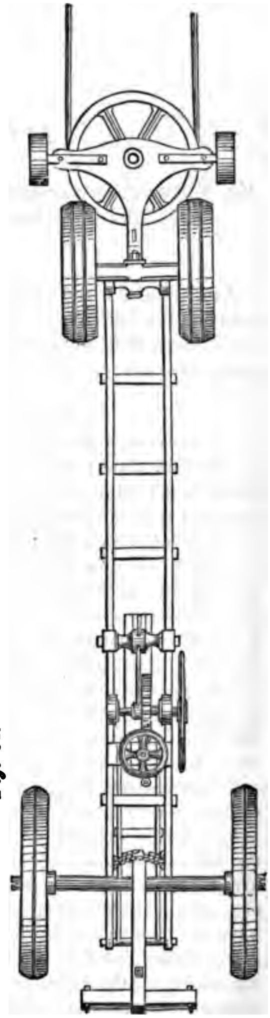


Fig. 78.

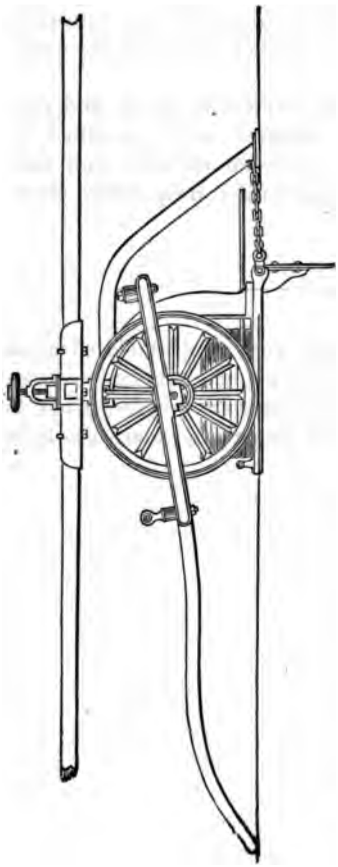
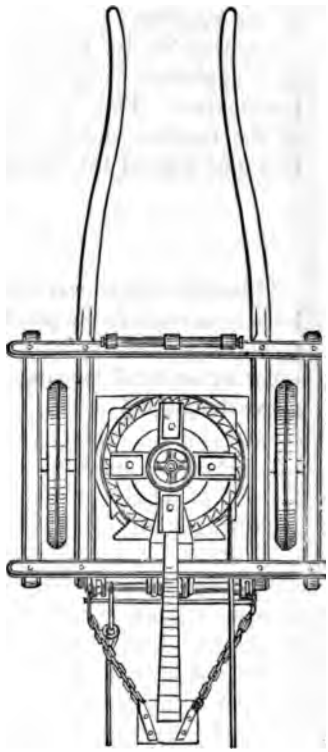


Fig. 79.



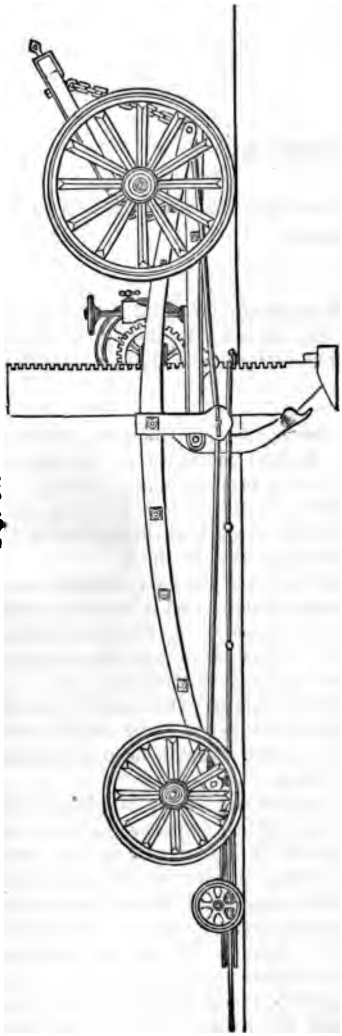


Fig. 80.

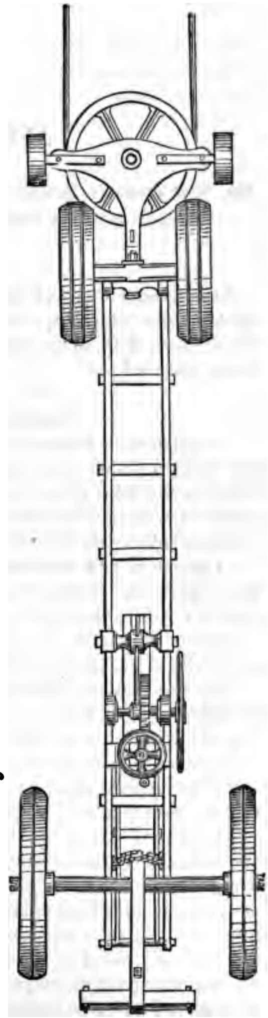


Fig. 81.

of all this district is so low that it is impossible to obtain any other natural means of drainage than into the river, as at present. To obviate this objection, it is proposed to treat the western district by a different method, which appears to me well calculated to overcome the obstacles arising out of this circumstance, namely, to direct the whole of the sewage to one point on the shore of the river near the entrance into the Kensington Canal, and there take means for separatiug the liquid and solid portion of the sewage before the former is discharged into the river. Experiments on a large scale with this process are now being made, and with such result that its ultimate success may be fairly deemed probable.

"I agree, therefore, with the recommendations made in this report as to the method to be applied to the western district, in consequence of its extremely low level.

"With the general lines of direction which have been selected for interception I also concur; but, in anticipation of the success of the method for extracting solid manure from the sewage, and its becoming remunerative, it is suggested, 'that considerations may arise seriously affecting the scheme proposed,' and a question is raised 'whether it would not then be advisable, on the seore of economy, to modify the designs presented for the middle and low-level sewers, and to abandon the chief portion of the line between the river Lea and Barking Creek.' In this I do not go to the full extent with Messrs. Bazalgette and Heywood, for, although the process for the manufacture of manure may prove successful, I do not think this probably would tend to, still less would justify, the delay of the construction of the middle level works. These seem to me to be absolutely necessary to rectify the present defective system of drainage, whatever shape the manure question may eventually take. I have already stated that the middle level is calculated, when properly dealt with, to ameliorate the evils so much complained of in so marked a manner that the execution of the lower level may perhaps safely be postponed for a time; but I can foresee no degree of improvement in the manufacture of manure in prospect that would tend to any material alteration in its construction, or position, or cost. It strikes at the root of many of the existing evils in the most direct manner, while it comprehends within its scope and influence so large and important a district, that I think no minor obstacle ought to stand in the way of its execution. The extension to Barking might, I think, be dispensed with, as suggested.

"If in extending and perfecting the drainage of London, the chief objects be the improvement of the general sanitary condition of the inhabitants and the purification of the Thames from noisome matter, *I cannot help* repeating that I regard the middle intercepting sewer as

one of the most important features of the scheme on which I am now reporting, and, indeed, without it either object, and the last especially, could only be very partially attained, for no arrangement in the extraction of the solid matter from the sewage that I can conceive would prevent the frequent discharge of the usual amount of noxious filth into the river.

"This can only, I believe, be avoided by the intercepting system being fully carried out, and no part of the proposed plan is more effective than the middle interception, and none can be so ill spared or postponed.

"I am induced to express this opinion somewhat decidedly, because, having had my attention called to several methods that have been proposed for the extraction of manure from sewage, I have been led to the conclusion that, instead of multiplying such establishments within the precincts of towns, as some contemplate, a complete system of interception, with the concentration of the manure process on a few points, is that which is best calculated to attain success.

"With reference to the dimensions of the proposed sewers, I have not been able to go into the details of the calculations, but, having examined the tabular statements attached to the engineers' report, and having received explanations from them respecting the directions of the flow in the various sewers intended to take place, I have every confidence in the correctness of their conclusions.

"I have only further to add, that I regard the design of Messrs. Bazalgette and Heywood as comprehending, in a very practical shape, all the essentially useful suggestions which have, from time to time, been made by engineers respecting the drainage of the metropolis; and I have no doubt whatever that if the commissioners be put in a position to carry it out, it will be found effective.

"I am, gentlemen, your obedient servant,

"ROBERT STEPHENSON.

'To the Commissioners of Metropolitan Sewers."

APPENDIX No. 3.

MAIN DRAINAGE OF LONDON. THE PROCEEDINGS FROM 1854 TO 1865.

For reasons stated in the Preface, it has been considered desirable to leave Mr. Dempsey's paragraphs untouched, so far as concerns the proceedings in relation to the Main Drainage of the metropolis, and to present in this place a succinct account of what has been done in the matter between 1854 and 1865.

The first important events after 1854 in regard to this subject, were the abolition or abrogation of the *Metropolitan Commission of Sewers*, the establishment of a new body with greatly increased powers, and the settlement once for all (whether for good or bad) of a multitude of vexed questions relating to the method of draining the metropolis. On August 14, 1855, the royal assent was given to the "*Metropolis Local Management Act*," a statute of enormous length, having 251 clauses and 100 large pages of schedules. By virtue of this Act, the parishes of the metropolis elect vestries, which are bodies corporate, either singly, or two or more parishes combined, in which latter case the combined vestries form a *District Board*. The vestries and boards, together with the Common Council of the city, elect representatives from among themselves, in certain proportions; and these representatives, to the number of 45, form a *Metropolitan Board of Works*. The Secretary of State selects a chairman from three persons named by the board.

The powers of this board are chiefly the control of the main drainage of the metropolis, the naming of the streets and the numbering of the houses, the widening of narrow streets, and the facilitating of street traffic. The area over which this power extends is that which has been adopted by the Census Commissioners of 1851 and 1861, and which gives a total in the last named year of 330,237 inhabited houses, and 2,803,034 inhabitants, in the metropolis. The board, to defray the charges of any works undertaken, is empowered to levy a rate on the same principle as the county rate, and to borrow money upon the credit of that rate.

The *Parish Vestries* and the *District Boards*, besides electing members to the Metropolitan Board of Works, have extensive local powers of their own. They manage all the minor sewers and drains subordinate to the main drainage. They control the paving, lighting, watering, and cleansing of the streets, and the erection of public conveniences. They have the powers of surveyors of highways. They may appoint crossing-sweepers. They appoint *Inspectors of Nuisances*, whose duties are decided by that title. And, lastly, they appoint *Medical Officers o*

Health, to report upon the sanitary state of the several districts and parishes; to ascertain the existence of epidemics and other diseases; to suggest means for preventing the spreading of these evils; and to take cognizance of the ventilation of churches, chapels, schools, lodging-houses, and other buildings of a more or less public character. To defray the cost of these works, the vestries and district boards are empowered to levy rates on the householders, under the three forms of *Sewers rate*, *Lighting rate*, and *General rate*.

So far, then, as concerns the present part of our subject, the Metropolitan Board of Works, elected by the parish vestries and the district boards, is entrusted with the general drainage of the metropolis. One important clause in the Act declares that "Such board shall make such sewers and works as they may think necessary for preventing all or any part of the sewage within the metropolis from flowing or passing into the river Thames, in or near the metropolis; and shall cause such works to be completed on or before the 31st December, 1860." Of course it was right to name a limit of time in this way; but the limit has been far exceeded. Another Act, in 1856, empowered the commissioners, acting in harmony with the parish vestries and district boards, to take all the requisite measures for forming parks, pleasure-grounds, places of recreation, and healthy open spaces in the metropolis; but it did not affect the power of the commissioners in reference to the main drainage.

It was known when the Act of 1855 was passed, that the Government, and most of the influential persons concerned, were favourable to the "Intercepting" scheme, as contrasted with the local or sectional schemes. But much valuable time was spent in discussion. Not only did the remaining portion of that year, but the whole of the years 1856 and 1857, pass away without definite results; and it was not until 1858 that an Act of Parliament was obtained, empowering the commissioners to carry out a specified system of metropolitan drainage. This Act, which received the royal assent on the 2nd of August, was framed after an immense deal of trouble. Considering that 80 million gallons of liquid refuse flow from the metropolis every day; that this vast bulk of water contains 400 tons of solid refuse; that 2,000 miles of sewers convey these abominations into the Thames by about 100 mouths; that considerably more than 100 square miles of area have to be provided for in some way or other; and that upwards of 80 miles of great intercepting sewers would have to be constructed, it is no wonder that embarrassments and difficulties should arise. But there were others of a more formal kind. By the former statute (1855), the *Board of Works and Public Buildings* had a veto on the plans of the *Metropolitan Board of Works* in all that concerned main drainage; and as the rival boards had rival engineers, with rival plans, matters came to a dead lock. Moreover, by the "*Thames Conservancy Act*" of 1857, the corporation

have certain rights conceded to them over "the soil of the Thames between high and low water;" and these rights give them a voice in many drainage questions. All difficulties of this kind were, however, at length surmounted, and the Act was passed.

The basis of the system adopted was the Interception, which had been more or less before the public since 1845. The Act did not instruct the commissioners to adopt any plan defined in the Act itself, but empowered them to adopt *a* plan, *some* plan, on their own responsibility. They were to be relieved from the absurd veto of the Commissioners of Works. They were empowered to spend 3,000,000*l.* sterling by the 31st December, 1863; to borrow this amount under their corporate seal, and to repay the principal and interest in forty years by a levy of 3*d.* in the pound on the annual value of the property in the district, in the manner of a county rate.

The curious course of procedure, therefore, had been this; that, in 1855, the Metropolitan Board of Works was formed mainly with a view to the drainage of the metropolis; that, in 1856 and 1857, all parties were disputing as to the best mode of doing this; that, in 1858, an Act of Parliament was passed, empowering the commissioners to spend 3,000,000*l.* on *some* plan for preventing the sewage of the metropolis from flowing into the Thames; and that the commissioners then had to give their final vote what that plan should be.

We have now, therefore, to give some account of the greatest system of town drainage ever yet commenced. The commissioners, in 1859, finally determined upon the Intercepting plan, with Mr. Bazalgette as their chief engineer. The reader is already acquainted with the general character of the plan in the foregoing paragraphs; and all that will be necessary, therefore, is, to show how far the results are likely to be modified.

The area that will be drained under this system, both of house-sewage and of rain-fall, extends to the enormous amount of 117 square miles, nearly equal to that of a quadrangular area 12 miles long by 10 broad. All the arrangements as to the outfall, &c., are made for a prospective population of 3,500,000, about 500,000 more than the *present* population of the included area. The whole of this drainage will then, as heretofore, flow into the Thames, unless some plan is adopted of utilising the sewage; but nearly the whole of it will enter the river many miles below London, under circumstances which, it is hoped, will prevent a return of the pollution upwards. There will be five great lines of sewer, more or less parallel to each other and to the river; and each of these sewers will receive all the drainage from so much of the district as is on a higher level than itself. Three of the main sewers are on the north of the Thames, and two on the south. The first three will converge at a point eastward of the metropolis, and then flow into the river near

Barking Creek; the last two will converge near Deptford, and flow on together to Crossness Point, between Woolwich and Erith. We shall now describe these great lines separately, under the names by which they are generally known, and shall give a few further details concerning them collectively.

Northern High-Level.—This commences in the Gospel Oak Fields, at the foot of Hampstead, and extends to Old Ford, by way of Kentish Town, the New Cattle Market, Highbury Vale, Stoke Newington, Hackney, and Victoria Park. It absorbs on its way the old offensive open sewer called Hackney Brook, which is now emptied and closed over. It crosses beneath the Great Northern, Tottenham and Hampstead, and North London railways, and Sir George Duckett's Canal. The fall commences at about 4 ft. per mile. It lies at a depth of 20 ft. to 26 ft. below the ground, and drains 14 square miles. The sewer is 4 ft. by 2 ft. 8 in. at the western or upper end, and gradually enlarges to 12 ft. wide by 9½ ft. high at the east end. The actual distance is about 8½ miles, but some small additional portions of sewers raise the length to 9½ miles. The engineer's estimate for this work was about 180,000*l.*; and the whole has been admirably finished by Mr. Moxon within the estimate.

Northern Middle-Level.—This commences at Counter's Creek sewer, near Kensal Green, and extends to Old Ford. It first passes nearly south from Kensal Green and Kensington Park to Notting Hill, and then along the Bayswater Road, Oxford Street, Bloomsbury Square, Clerkenwell, Old Street, and Bethnal Green to Old Ford. The length, with branches, is about 12½ miles, half of which is tunnelling; and for 2 miles it passes under houses and other private property. The size of sewer, as in the former case, varies from 4 ft. by 2 ft. 8 in. to 12½ ft. by 9 ft. The gradient varies from 2 ft. to 25 ft. per mile; and it lies at a depth varying from 30 ft. to 40 ft. below the surface. Mr. Bazalgette's estimate for this great work was 280,000*l.* Mr. Rowe contracted for it in February, 1860, at a price of 264,000*l.*; but he broke down after an expenditure of 12,000*l.*; and a new contract was made in December with Messrs. Brassey and Co. for 330,000*l.* This portion of the work has been beset by immense difficulties; for, owing to a paucity of plans of existing sewers, water-pipes, and gas-pipes, the excavators had to feel their way inch by inch under the roadway of Oxford Street and other places. At another place the Regent's Canal burst into this sewer, retarding the works for a considerable time.

Old Ford Storm Overflow.—The High and Middle-level sewers converge at Old Ford, where some remarkable works have been constructed. The *Penstock Chamber* consists of a large receptacle below, and machinery rooms above. The arrangements are such, that when the High and *Middle-level sewers* are supercharged after heavy rain, the surplus water

is diverted, in the Penstock, into a short channel which flows into the river Lea, permitting only the usual average quantity to flow onwards towards the Thames. The proportion thus diverted may be varied at pleasure. This is a more important matter than would at first be supposed. Four times as much sewage passes through the London sewers at noon as at midnight; the maximum flow being about equal to a rain-fall of a quarter of an inch in depth in twenty-four hours. But besides this source of inequality, the quantity is much exceeded in rainy weather, at which time the rain-fall often greatly exceeds in bulk the sewage itself. It would have been very difficult and enormously expensive to construct the sewers large enough to carry off all the storm waters as well as the sewage; and therefore the *existing* main sewers, as well as the river Lea, are to be occasionally made use of as storm overflows, to carry the rain-fall to the Thames by channels different from those of the new sewers. The whole of the drainage collected by the Upper-level was diverted by the mechanism of the Penstock into the Lea in 1862, until the works at Barking were finished. The value of the system was further felt in 1862, when an irruption of the Fleet sewer into the Underground Railway in Victoria Street took place. The injury would have been much greater, had not the upper waters been diverted to Old Ford. It may suffice to show the formidable nature of some of these works, when we say that between Old Ford and Barking the High and Middle-level sewers have had to be carried, by iron aqueducts supported on columns, across no less than six branches of the river Lea, across the East London Waterworks Canal, and under and over four lines of railway. The works for the Old Ford Penstock Chamber were included in Mr. Moxon's contract for the High-level sewer.

Northern Low-Level.—This begins by a junction with the Ranelagh sewer at Chelsea, which it will connect with the Victoria Street sewer; then, approaching the Thames at Whitehall, it will continue near the embankment to the City; whence it will pass by way of Tower Hill, Stepney, Limehouse, and Bromley, to West Ham. At this last-named place it is to be joined by the High and Middle-level sewers. One grave difficulty has led to the delay of these works. According to the original plan, this sewer was to have been carried beneath the roadway of the Strand, Fleet Street, Ludgate Hill, &c., at a depth varying from 30 ft. to 50 ft. below the surface; but it was felt that the execution of the works would be an insupportable nuisance to the inhabitants, and that the obstructions to trade might give rise to formidable claims for compensation. It was even feared that St. Paul's Cathedral might be endangered by such deep excavations near its foundations. It was therefore determined to combine the scheme for a Low-level sewer with one for a Thames Embankment. Accordingly an Act was obtained in 1862, which enables the Metropolitan Board of Works to carry the Low-

level sewer close to the proposed embankment, in the bed of the Thames itself, from Whitehall to Blackfriars Bridge. There will be difficulty enough to decide how to carry the sewer through the City; but the double scheme will at all events save the Strand and Fleet Street from the threatened disturbance. How the sewer and embankment will be combined is explained in a later page.

The Northern Outfall.—We have traced the High and Middle-level to Old Ford, and have now to describe their course over the Essex Marshes. The *Northern outfall* extends from Old Ford to Barking Creek, where the river Roding enters the Thames, a distance of about 5½ miles. The route is by way of Stratford, West Ham, Plaistow, and East Ham. It comprises two parallel channels from Old Ford to West Ham, mostly brick arches of 12 ft. by 9 ft., but partly iron tubes of great magnitude. At West Ham the Low-level sewer will join them; but as the sewage will in this be at a much lower level than in the others, it will be pumped up by powerful machinery. The three sewers will then run in three distinct and parallel channels, formed of the best brickwork, in an embankment above the general level of the ground. The three channels will be 14½ miles in all. In order to ensure permanence of structure, and to avoid a thick bed of peat which underlies the surface in the Plaistow and East Ham marshes, a concrete foundation for the embankment has been made, in some places 25 ft. below the surface. The triple sewers pass under one and over two lines of railway. For a mile and a half the embankment is built upon transverse arches, the piers of which rest upon a deeply laid bed of concrete. Mr. Bazalgette's estimate for this remarkable tripartite system of vast channels was 635,000*l.*; and Mr. Furness took the contract in 1860 for 625,000*l.* The work is considered to rank among the best specimens of brickwork ever seen—almost as highly finished as if intended to meet the eye of a connoisseur, instead of being permanently buried out of sight. It has been wisely determined that the cheapest as well as the best way in the end will be to do this work thoroughly once for all.

The Barking Reservoir and Sluices.—The sewage conducted along the three fine lines of channel just described is received at the *Outfall Station.* This consists mainly of a vast covered brick reservoir, 14 acres in area and 20 feet deep, and would, if needed, contain double the quantity of twelve hours' sewage from all the northern sewers. It is so roofed with brick arches and earth, as to prevent the escape of effluvia. From this reservoir the sewage will flow into the Thames during the first two and a half hours of ebb; that is, for two hours and a half after high water. It is calculated by the engineer (and on the correctness of this calculation depends much of the success of the whole scheme) that as the point of discharge is 12½ miles below London Bridge, the outgoing tide will carry the sewage too far away to allow it to flow up

to London again at the flood tide; especially as the bulk of water opposite the outfall is very great, and as the flow downwards is very forcible during the first two or three hours after high water. It is supposed that the very last gallon of each outflow will have reached 12 or 13 miles below Barking Creek, or 25 below London Bridge, before the tide begins to flow upwards again. The mains carry the sewage from the reservoir far out into the bed of the river, so as to insure its mixing with as large an amount of water as possible. Mr. Bazalgette's estimate for the works at this outfall station was 170,000*l.*, and Mr. Furness took the contract for 164,000*l.*, in January, 1863. It is probable, however, that these works may be made in some way contingent upon any future scheme for the utilisation of sewage. Mr. Bazalgette, pending the discordant arguments on this subject, lays his plans for the discharge of the whole of the sewage into the Thames; but the commissioners have purchased 50 acres of land adjacent, to be prepared for any future scheme of sewage utilisation.

Western Drainage.—The western part of the Metropolitan area, north of the Thames, is much of it at so low a level that the three great intersecting sewers cannot well accommodate it. It is, therefore, treated by Mr. Bazalgette as a distinct system. The districts comprised within it are Acton, Hammersmith, Fulham, Kensington, Chelsea, Brompton, &c. This system comprises several portions. The *Acton Branch* extends from Acton Bottom to Notting Dale, along the Uxbridge Road. It comprises about 1½ mile of small sewers, and descends 4 ft. per mile, at an average depth of 15 ft. below the surface. The *Ranelagh Storm Overflow* is a sewer commencing in the Bayswater Road, passing through Kensington Gardens and Hyde Park, and joining the Ranelagh sewer at Knightsbridge. It connects the Middle-level system with the Western system. Its chief purpose is to carry off storm overflows, that would otherwise trouble the district, and overfill the Middle-level sewer; but another purpose is to relieve the Serpentine from foul water that used to enter it during those overflows. This subsidiary sewer is a little over a mile in length. The sewer is a 9 ft. barrel, at a depth of 11 to 44 ft. beneath the surface, and with a fall of 12½ ft. per mile. These sewers vary from 3¾ ft. by 2½ to 4½ ft by 4½. It was at first intended to form a covered reservoir near the banks of the Thames, by the side of the Kensington Canal, with arrangements for deodorising the sewage before allowing it to pass into the Thames; but the inhabitants of the neighbourhood objected so strongly to the plan that the commissioners appointed a committee to consider and report upon it. Meanwhile these western sewers have been proceeded with, leaving the question of the outfall in abeyance.

Southern High-Level.—The whole of the immense works hitherto described are, or are to be, north of the Thames. We have now to

notice those on the south. Here, unlike the north, there is no *Middle-level;* the nature of the district being satisfied with a *High-level* and a *Low-level* sewer. The *High-level* extends from Clapham Common to Deptford Creek, a distance of 9½ miles, by way of Brixton, Camberwell, and New Cross. It varies in section from 4½ ft. by 3, to 10½ ft. by 10½, and lies at a depth varying from 10 to 50 feet beneath the level of the ground. Mr. Bazalgette's estimate was 212,000*l.*; the contract was taken conjointly by Messrs. Holling & Co. and Messrs. Lee and Bowles for 217,000*l.*, and the works are completed. Connected with this High-level is a branch from New Cross to Dulwich and Norwood, superseding in its way an offensive open channel called the *Effra sewer.*

The Southern Low-Level extends from Putney to Deptford Creek, by way of Wandsworth, Battersea, Vauxhall, Lambeth, Southwark, and Rotherhithe, a distance of about 9¼ miles, with a Bermondsey branch from the Spa Road. In some of these works on the south side the difficulties have been most harassing. At one place the water flooded in upon the works at the rate of 8,000 gallons per minute, taxing the contractor's skill to the utmost. Although it is customary to speak only of two levels on the south of the river, it would give a better idea of the system to have regard to three—Putney to Deptford, Clapham to Deptford, and Norwood to Deptford—all rising at different levels, but all coming to the same level at Deptford.

Deptford Pumping Station.—On account of the low level of most of the ground near the south bank of the Thames, the sewage from the Low-level sewer will flow to a point far too deep to enter the river; indeed, it is stated that nearly one half of Lambeth, Bermondsey, and Rotherhithe is 6 ft. below high-water level. Hence it becomes necessary to pump the whole of it up to a higher level; and for this purpose steam-engines, boilers, furnaces, pumps, pump-wells, chimneys, coal-sheds, &c., are provided at Deptford. These works alone have cost 140,000*l.*

Southern Outfall.—This consists of about 7½ miles of sewer, 11½ ft. in diameter, at depths varying from 17 to 80 ft. below the surface, and with a fall of 2 ft. per mile. At Woolwich, it is in some places full 80 ft. beneath the surface, and of course made wholly by tunnelling. It extends from Deptford Creek to Crossness Point, in the Erith Marshes, under Greenwich and Woolwich, and across Plumstead Marshes. At Deptford it receives the contents of the High-level sewer by gravitation, and those of the Low-level by pumping.

The Crossness Reservoir and Sluices.—At the point of junction with the Thames, 14 miles below London Bridge, there is a system analogous to that at Barking Creek, but more costly to work on account of the difference of levels. There are four double-acting condensing and rotative engines of 125 horse-power, working eight pumps, 7 ft. in diameter, with a lift varying from 10 to 34 ft.; and the works connected

with the flowing into the river of the sewage thus pumped up comprise engine and boiler houses, reservoirs, river-walls, shafts, coal-sheds, &c. The pumping power is equal to that of raising 25,000,000 cubic ft. per day to the level of the outfall. These works on the south side of the river are very costly: the Deptford and Crossness constructions, and the connecting sewer between them, will cost no less than 800,000*l.*, irrespective of the southern high and low-level sewers. The reason is, that the whole of the sewage has to be pumped up before it can enter the Thames, whereas at Barking it flows by gravitation to the proper level. There is at Crossness a reservoir 5 acres in extent: connected with it are three systems of channels, one above another—the lowest to bring down the sewage from the sewer to the pumping-well; the highest to convey it into the reservoir by pumping; and the middle one to discharge it from the reservoir into the river. There is also provision for carrying off the storm-waters by another channel. The culverts for carrying the sewage from the great main sewer to the pumping-well are sufficiently large for a railway train to run through, and a troop of mounted Lifeguardsmen might do the like. The sewage passes through gratings, or strainers, before it reaches the pump-well, formed of a kind of portcullis working on massive hinges secured in the masonry. The strainings thus arrested—consisting of dead cats and dogs, and all the miscellaneous bulky substances that find their way into the sewers—fall into a capacious stone receptacle. A large wheel, carrying buckets on the periphery, rotates in this receptacle, and dredges up the *filth* (as these solid matters are called), and deposits it in the *filth chamber*, whence it is flushed into the river at low tide. The bottom of the pump-room is 17 ft. below low-water mark. This shows how formidable will be the work allotted for the pumping-engines to perform. Indeed, Mr. Bazalgette has declared that if the *northern* drainage had to be pumped up in the way which is thus necessary for the southern, he would have shrunk from incurring the vast working costs that would be involved; and, in fact, he would not have recommended the plan at all. When the sewage has reached the reservoir (which has a floor of Portland stone, and a roof formed of brick arches resting upon brick piers), it will accumulate to the extent of 20,000,000 gallons (if full), and will then be let out into the Thames for about two hours after each high-tide, day and night. The reservoir will contain at one time much more than twelve hours' sewage from the whole of the metropolis south of the Thames, with a sufficient extra capacity for contingencies.

In 1861 and 1862 the Metropolitan Board of Works invited many hundred peers, members of parliament, and other influential persons, to visit the works, and see for themselves the nature of these very novel operations. On the 18th July, 1863, another of these inspections took place, by four hundred distinguished persons. Mr. Bazalgette explained

everything that could be explained in a short oral address, and then announced that all the northern drainage, except the Low-level sewer, would be finished about the end of 1863—that by the autumn of 1864 the whole of the southern drainage would be finished—and that by the end of 1866 the completion of the northern Low-level sewer and the Thames northern embankment may be expected. (The progress has not been quite so rapid as Mr. Bazalgette at that time anticipated.) After the visitors had inspected the vast works at Crossness Point they passed over by steamer to Barking Creek, where the following operation took place, as described in the daily newspapers:—"The contents of the High-level sewer, bringing down the sewage of Hampstead, Highgate, Kentish Town, Holloway, Hackney, Bethnal Green, &c., was turned on for the first time direct into the Thames. For some time past it has been discharged through the Storm Overflow into the river Lea. The complaints against the commissioners for spoiling the navigation of the pleasant little river induced the board to lay down a temporary iron duct, which conveys the sewage direct into the river Thames from the end of the great sewer, without leading it through the reservoir. To those who have faith in the value of this material as a liquid manure, it must have been grievous indeed to see this gushing, roaring, black, and stinking stream mixing in the broad waters of the Thames. Others, however, not so absorbed in considerations of the economical value of this fertilising stream, regarded it as the first great triumph of the system of main drainage."

Considering the immensity of the work, it cannot be matter for surprise that the cost will exceed the estimates. Since the commencement of the commissioners' operations, in 1858, the wages of bricklayers and the prices of bricks have risen considerably. It has been found that between 1858 and 1863 wages had risen 1*s.* or 1*s.* 6*d.* per day for bricklayers, and 6*d.* or 1*s.* per day for excavators and labourers. The best stock bricks, with which most of the work has been done, rose from about 26*s.* to 40*s.* per thousand; and every kind of cement had risen in price also. These augmentations of wages and prices were due mainly to the unexampled quantity of brickwork executed in and near London within the last few years. The Metropolitan or Underground Railway, the Metropolitan Extension of the Chatham and Dover Railway, the Charing Cross and Cannon Street Extensions of the South-Eastern Railway, and the Finsbury Extension of the North London Railway, besides the International Exhibition building and other public structures, and the new dwelling-houses and edifices (there were 24,000 new houses built in the metropolis between the two takings of the census in 1851 and 1861), all combined to enhance the market value of materials and labour in the building trades. The contracts taken for the main drainage in 1861, 1862, and 1863 were at higher terms than those taken in 1858.

1859, and 1860, on this account. Hence it resulted that Mr. Bazalgette found his estimates would be exceeded. The Commissioners of the Board of Works had, by the Main Drainage Act of 1858, obtained power to raise 3,000,000*l*., to be paid by a tax or rate on the house property within the metropolitan area. The Bank of England has advanced this sum, at the low rate of 3¾ per cent. interest. In June, 1863, the commissioners announced to the Treasury that, partly owing to the rise in labour and materials, and partly to the necessity for additional works, a further addition of more than a million sterling would be necessary. After a little correspondence, the Treasury agreed to the introduction of a Bill for increased parliamentary powers; and this Bill has since become law. The commissioners may raise 1,250,000*l*., which the Bank of England agrees to advance at 3¾ per cent. It is a curious proof of the increase in the value of property in London, that the commissioners now believe they will be able to pay off the whole 4,250,000*l*. in forty years—the same period which in 1858 they believed would be necessary for paying off 3,000,000*l*. The duty is 3*d*. in the pound on the rated rental of the property within the metropolitan area. It produced 150,389*l*. in 1858-59, and gradually rose to 157,075*l*. in 1862-63. Calculating on a similar rate of increase in future, the commissioners estimate that by the year 1898, or forty years from 1858, they will have received an aggregate total of 7,560,000*l*. This would pay off the debt of 4,250,000*l*., together with 3,233,465*l*., the calculated interest, and leave a small surplus. As the Treasury will guarantee the whole of the principal and interest, they will virtually claim control over the due collection and disbursement of the rate. The new Act of 1863 gave the commissioners an extension of time until the end of 1866, on the ground that it will be impossible to finish the Low-level sewer except in connection with the Thames embankment.

Should the anticipations of the engineer be realised, it will unquestionably be one of the greatest works of ancient or modern times. Even in an industrial point of view it is very remarkable; for, by the time all is finished, the works will have absorbed 300,000,000 bricks, and 800,000 cubic yards of concrete, while the excavations will have amounted to 4,000,000 cubic yards of earthwork.

Among the many difficulties which the engineer of the Main Drainage has had to meet, is that connected with new railway schemes. In 1863 there were no fewer than thirty-three distinct plans for railways in the metropolis; and when Mr. Bazalgette came to examine them, he found that they would cut his sewers all to pieces, if constructed according to the deposited plans. One would have diverted the great Fleet sewer wholly out of its present direction for a considerable distance; while others had been planned so recklessly that it would be difficult to see how the sewers could be managed at all. Happily, most of the schemes fell

to the ground at one or other of the parliamentary stages; and in those for which Acts were obtained, clauses were introduced bearing reference to the safety and efficacy of the Main Drainage. Difficulties of a similar kind afterwards arose in relation to the railway projects of 1864 and 1865.

APPENDIX No. 4.

EMBANKMENT OF THE THAMES.

Although the embankment of the Thames, now (1865) legislatively sanctioned in reference to both banks of the river, is intended mainly to increase the road communication, east and west, through the metropolis, and to deepen and otherwise improve the river current, yet the intimate alliance which it has with the great intercepting main drainage scheme, on account of the line selected for the Low-level northern sewer, renders desirable some account of the matter in this place. We shall therefore rapidly trace the history of the subject, notice the extraordinary variety of projects to which it has given rise, and describe the final result to which those projects have led.

Just about a century ago plans began to be proposed for embanking one or both sides of the river at London; and they have been poured forth at intervals ever since. The object was not in the first instance to protect the river from pollution, but to improve the shores in an architectural point of view, and to facilitate traffic. So long as cesspools were used instead of sewers, the river remained comparatively clean; for the contents of such receptacles frequently found their way upon the land for manure. But when sanitary reformers urged upon the government, as a measure of public health, the desirability of encouraging the construction of sewers instead of cesspools, then did the Thames of necessity become polluted, seeing that there is no other channel through which the contents of the sewers can be conveyed out to sea. All the earlier schemes for embanking the Thames, as we have said, had other objects in view than the preservation of the water in purity; but with the present century the plans gradually became more comprehensive in their scope. A committee of the House of Commons was appointed quite early in the century to examine schemes for improving the river in various ways. Among them was one by Mr. Jessop for forming a river wall at some distance beyond the existing shore; filling in the space behind it with ballast dredged from the bed of the river; forming in this way an embankment from Blackfriars Bridge to the Tower; building wharves

and warehouses on the embankment; dredging the shoals in that part of the river; and selling the reclaimed land behind the embankment to pay for the works. The plan was full of ingenuity, but nothing came of it. Twenty years afterwards, when old London Bridge was about to be replaced by a new one, Mr. James Walker was requested by the Corporation to report on the probable effect of that change on the river and its banks. His opinion was that the effect would be rather beneficial than otherwise. Then, in 1824, came forward Sir Frederick Trench's scheme for embanking the Thames. He proposed to embank the north shore from London Bridge to Westminster Bridge, and to render the embankment available as a public thoroughfare. A bill was brought into Parliament to effect this object, by means of a public company; but without success. Next year he enlarged his plan, proposing to make an embankment from London Bridge to Scotland Yard, 80 ft. wide, with a carriage-way in the middle, and footpaths on either side; to continue this by another embankment, 110 ft. wide, from Scotland Yard to Westminster Bridge, to be surmounted by a terrace-crescent of handsome houses; to form a basin behind the embankment, 7 or 8 acres in area, for commercial purposes; and to construct roads to connect the embankment with the Strand. The scheme was one of much boldness; but, like its predecessor, it fell to the ground. In 1831 and 1832, Sir John Rennie and Mr. Mylne, at the request of the Corporation, reported on the practicability of improving the Thames by equalising in some degree the depth and the width at different points. They proposed about 12,000 ft. of quay wall on the south side, from Southwark Bridge to Westminster Bridge, and 7,000 ft. on the north side. They calculated, as other engineers had previously done, that the rental of the reclaimed land behind the river wall would pay for the whole enterprise. The Corporation, however, did nothing further in the matter. Again, nine years afterwards, engineers went over the old track, and took up again the idea of a river wall or embankment. In 1840 the Corporation, reproached for doing nothing, answered the reproach by commissioning Mr. Walker to prepare a comprehensive plan. He found on examination that, by the removal of the bulky piers of old London Bridge "the velocity of the stream had increased, the depth of water had decreased, and shoals appeared more and more above the surface; the piers of Blackfriars and Westminster bridges were becoming undermined; and the general effect had been to render the inequality of the river greater than ever, by deepening the narrow parts and shoaling the wide." Mr. Walker believed that the Thames, even at the narrowest part, is wide enough for all the traffic, if well organised; and his proposal was, to bring the river to something like an equality of width by means of embankments. The width is a minimum of 600 ft. opposite the Millbank Prison, and a maximum of 1,480 ft. opposite Buckingham Terrace. He

proposed that the maximum should nowhere exceed 870 ft. The embankment was to consist of a river wall of brick or stone, filled in behind with soil dredged up from the bed of the river; and Mr. Walker estimated (as other engineers had estimated before him) that the rental of the reclaimed land would pay for the works: the soil would form good building ground behind the wall, instead of shoaling the river itself. This well-concocted scheme fell to the ground, owing chiefly to the opposition of wharfingers and others interested in river-side property.

We now approach the period when Royal Commissioners began to take up this Thames question. In 1842 a commission was appointed "to inquire into and report upon the most effectual means of improving the metropolis, and of providing increased facilities of communication." As far as concerned the Thames, the commissioners examined plans by Sir Frederick Trench, Mr. Walker, Mr. Page, Mr. Martin, and others. Trench's plan was for an embankment, with a railway elevated above it on columns; a promenade between the columns; a foot-pavement between the covered walk and the river; stone landing-stairs at intervals; and a road for vehicles on the other side of the walk. Mr. Walker's plan comprised a continuous quay on the northern side of the river, about 4 ft. high; and the owner of every wharf was to have the portion of quay fronting his property on certain terms to be agreed upon. Four basins behind the quay were to be constructed for barge traffic, with four openings through the quay itself. This plan proposed neither a roadway nor a large area of reclaimed land behind the quay, and was in these particulars less comprehensive than his earlier plans. Mr. Page's plan was for a quay with numerous water-openings leading to floating basins, or tidal docks, behind it. Every water-opening was to have a bridge over it, so that a continuous roadway might be formed along the quay. Mr. Martin's plan was one of the first which embraced provisions for a great sewer, in addition to the other objects of an embankment, and on that account it deserves notice, as a sort of precursor of the plan now actually being adopted. He proposed the construction of a great sewer to receive all the drainage from the adjacent parts of London, and carry it down to Limehouse, where it would be solidified as agricultural manure; a line of quay above the sewer for general traffic; a line of terrace above the quay for foot passengers; and colonnaded wharves upon the quay, at certain busy places, to land merchandise, but without disturbing the continuity of the quay. It is worthy of remark that, while Mr. Martin's plan resembled the one now actually adopted, in combining a low-level sewer with an embankment, Mr. Page's resembled it in containing a provision for paying for the works by a tax upon all coals brought within the metropolitan area.

London was doomed to another postponement of these excellent

improvements. The commissioners issued voluminous reports; but, through various causes, nothing was done—excepting the embanking of the northern shore of the river in the neighbourhood of Pimlico, chiefly through the energetic exertions of Mr. Thomas Cubitt, acting for or with the Marquis of Westminster.

In 1855 Parliament was flooded with railway schemes, many of which attacked the Thames in singular ways. Mr. Lionel Gisborne, Mr. Beaumont, Mr. Bird, Mr. Taylor, and Mr. Hawkshaw, all had schemes for combining railways in some way with embankments of the Thames, but without any arrangements for sewers. The House of Commons appointed a committee to investigate all these schemes, and this committee rejected every one of the plans that affected the Thames. And thus another year was lost. So, indeed, were lost the years 1856, 1857, 1858, and 1859, in regard to any definite plans for embanking the Thames. There were, however, proceedings in relation to the main drainage of the Metropolis, and others in relation to the temporary purification of the Thames water. The first we have already described in another part of the Appendix, and the other we will briefly notice in this place. As the water of the Thames had been getting more and more foul every year, it exhaled more and more noxious odours, especially in hot weather; until at length our judges at Westminster Hall "smell'd" the river all day, and our legislators at the Houses of Parliament all the evening, and half through the night. Mr. Goldsworthy Gurney, superintendent of the arrangements for warming and ventilating the Houses of Parliament, was requested, in 1857, to see what could be done in the matter. Mr. Gurney reported that the solid portion of sewage, being heavier than water, subsides permanently after being driven to and fro a few times by the flood and ebb tides, and forms a portion of the bed of the river; inasmuch as the black, slimy mud that we see at low water contains solid sewage as one of its constituents. No wonder, then, that such an abominable mixture should give forth offensive odours; the wonder would be if it did not. This applies to the part of the river above London Bridge, into which sewage can flow from the sewers only for a few hours before and after low water; it need not necessarily apply to the Thames about Barking and Erith, especially when the sewage flows into the river soon after high water, as in the Great Intercepting Drainage System.

Mr. Gurney conceived that if he could obtain a mastery over the banks of the river he could greatly lessen the offensive state of the water; even though the old sewers continued to pollute the river. By straightening and deepening the portion of the bed between high and low water levels, he expected to get rid of many eddies, slacks, and retrograde movements, which cause the retention of solid refuse. He proposed to deepen the shallows near the shore and to round off projections; then

to form a breadth of 50 yards of solid, sloping banks on either side of the river, with an inclination of one in twelve from the present shore down to low-water level; then to dredge a deep channel, 30 yards in width, immediately outside or beyond each of these slopes. The gravel dredged up would furnish materials for the sloping banks. The middle of the river he would leave untouched; the two deepened channels would form the water ways for river steamers. The theory on which this plan was based was, that the slopes of the banks would cause all mud and solid refuse to flow down into these channels; that the depth of the channels would cause a current sufficiently strong to carry down the refuse to the sea; and that thus the Thames would gradually become cleaner and more salubrious. Mr. Gurney further proposed, as a means of lessening the offensive odours perceptible at and near the mouths of the sewers, to *trap* those mouths, or to close them with valves of such construction as to permit the passage of solid and liquid sewage, but not gases. As the noxious gases would thus be confined within the sewers themselves, he further recommended that special openings should be made at spots near the mouths of the sewers for burning the gases, they being inflammable when mixed in certain ratio with atmospheric air. Mr. Gurney's plan, submitted to the Commissioners of Public Works in 1857, underwent their consideration during the winter; but nothing was practically done by Mr. Gurney, except lessening the offensive odour near the Houses of Parliament, by throwing down chloride of lime into the sewers.

The next stage in this matter was the appointment of a committee of the House of Commons in 1858, to investigate plans "for the purification of the River Thames, especially in the immediate vicinity of the Houses of Parliament." Judging from the constitution of the committee, it ought to have produced good results, seeing that it comprised the names of Lord Palmerston, Lord John Russell, Sir John Shelley, Sir Benjamin Hall, Mr. Robert Stephenson, Mr. Joseph Locke, and Mr. William Cubitt, besides others of less note. Mr. Gurney was the chief witness examined, and he presented in great detail the plan just described. Other engineers, however, handled his scheme with great severity. Mr. James Walker believed that Mr. Gurney's sloping banks would become covered with mud in the wide parts of the river; that the dredged channels would fill up again; that one deepened channel in the middle would be better than two near the sides; that the muddy deposit could not be removed unless a system of embankment were adopted; and that the offensive odours of the metropolis would not cease so long as any of the sewers entered the Thames thereabouts. Mr. Bidder expressed his opinion that the suggested channels would require constant dredging, to remove the gravel that would otherwise silt them up; that the navigation of the Thames would be incommoded by these artificial

irregularities of bottom; that deposits of mud would form on the sloping banks; that trapping the sewer mouths, burning the gases in shafts, and all the other parts of the plan, would involve a wasteful expenditure of money, as they would only be temporary expedients even if useful at all; and that the only good plan was a system of drainage which would carry the whole of the refuse of London into the Thames at a point far below the limits of the metropolis. Mr. Haywood, engineer to the City Commission of Sewers, contended that the ventilation of the sewers would cost annually a sum so enormous as to be insupportable; that the existing air-shafts and gulley-holes must be trapped as well as the mouths of the sewers, to give the system a fair chance; and that only a small portion of the deleterious gases could be decomposed by burning. In short, although a few civil engineers gave a favourable opinion of Mr. Gurney's plan, the balance of evidence was decidedly against it. The committee thereupon rejected it. The investigation led, however, to a strengthening of the hands of the Metropolitan Board of Works, and to an adoption of that scheme which we have already described for the main drainage of the Metropolis.

The plans for embanking the Thames remained in abeyance for some time. Mr. Gurney's deodorising of the existing sewers was abandoned; the great intercepting drainage was commenced; and the embankment schemes slept a while. It became, nevertheless, evident that the Metropolitan Board of Works were favourable to such an embankment, in connection with their Low-level sewer. There was a very general concurrence of belief that if there were a river wall, filled in behind with solid earth, the advantages would speedily become great. By narrowing the river at certain wide parts, the current would be rendered more equable; by straightening the line of shore, it would increase the scouring action of the stream; by shutting off the strip of ground between high and low water, it would prevent the formation of mud-banks; by giving adequate breadth to the embankment, a terrace roadway might be formed at the top; by enclosing and drying the space now occupied by sand-banks, new building ground might be obtained; and by having a permanent wall running along a line in advance of the present limit of the river-side houses, there would be a barrier, behind which a low-level sewer might be constructed at any desired depth, without passing under the houses and roadway of the Strand and Fleet Street. The old idea, growing in many ways since the days of Sir Christopher Wren, had been clouded from time to time by other plans; but it was pretty certain to meet with proper attention at last.

The year 1859 passed over without any decisive results in reference to the Thames embankment; but in 1860 a committee of the House of Commons collected a vast body of evidence, and published a bulky Blue Book, illustrated with many valuable maps and plans. The chief pro-

jects for embanking the Thames were eight in number, concerning each of which we will say a few words:—

1. Mr. Fowler proposed an embankment, 80 ft. wide, from Westminster to Blackfriars, to carry a road and a railway. The line would be continued (though not on an embankment) to Farringdon Street station at the one end, and to Pimlico station at the other; and there would also be a new street from Blackfriars to Cannon Street. Three docks would be formed behind the embankment for barges, with a water area of 8 acres. The capital was to be provided, partly by the Government or by the local authorities, and partly by a company, who would work the railway.
2. Mr. Lionel Gisborne proposed to embank both sides of the river from Westminster Bridge to London Bridge, on the supposition that the southern bank would be injured if only a northern embankment were made. He looked to a large rental for the reclaimed land behind the two embankments.
3. Mr. Sewell proposed a railway on iron pillars, following nearly the low-water line, with a low-level sewer under it, and openings between the pillars for barges to reach the same water-area that is now open to them.
4. Mr. Edmeston proposed an embanked road and railway following nearly the high-water level, the whole of the barge trade to be conducted outside it.
5. Mr. Bird proposed a tunnel railway from Pimlico station to Scotland Yard; a railway, partly elevated and partly submerged in an iron tunnel, from Scotland Yard to Queenhithe; an embankment and roadway from Scotland Yard to Blackfriars; and the finishing of a long-intended line of new street from Blackfriars to Cannon Street.
6. Mr. Bidder brought forward a plan in which he had been assisted by Mr. Harrison and the late Mr. Robert Stephenson. It comprised the following elements—an embankment from Westminster Bridge to Southwark Bridge; arches to raise a roadway to a level with those bridges; a low-level sewer beneath the embankment; large areas of reclaimed land to be given to Somerset House and the Temple; about 12 acres of docks behind the embankment; an extensive surface of reclaimed land to be let or sold for warehouses and cellars; and a double tramway for large omnibuses on the embankment. The plan also contemplated an embankment on the south side of the Thames the whole way from Battersea Park to London Bridge.
7. Mr. Page proposed an embankment from Pimlico to Queenhithe, for the most part so low as not to intercept the view of the river from the existing houses; the road to be on the embankment.

26 acres of dock-space to be formed behind the embankment; certain portions of the reclaimed land to be laid out as pleasure-grounds; tidal gates to be constructed in the embankment, to admit barges into the docks; a low-level sewer to be made under the embankment; and the embankment to be broad enough to admit a tramway.

8. Messrs. Bazalgette and Hemans proposed an embankment from Westminster Bridge to Queenhithe; a road on the embankment 100 ft. wide, to pass *under* Hungerford, Waterloo, and Blackfriars Bridges, and inclined roads to connect the embankment with the levels of those bridges. The embankment would be formed by cylinders and sheet-piling, like new Westminster Bridge, filled in with earth; a low-level sewer would be formed beneath the embankment, and behind it would be five docks, varying from 100 to 300 ft. in width, covering 21 acres, and entered by several tidal gates.

All these plans, and many others, engaged the attention of the committee. As a result, the committee did not recommend any plan in particular, but only some plan to be executed by the Metropolitan Board of Works, under sanction of an Act of Parliament to be obtained for that purpose. They recommended a postponement for a time of any southern embankment, and a limitation of the length of the northern embankment to the space from Westminster Bridge to Blackfriars. They proposed that the cost should be defrayed out of the coal and wine duties collected in the City.

No Act for this purpose was obtained in 1861; but a royal commission was again appointed to examine and report upon all the schemes that they could get hold of. The commissioners were Sir William Cubitt, Sir Joshua Jebb, Captain Galton, Mr. Burstal, Mr. Hunt, Mr. McLean, and Mr. Thwaites. They examined no less than fifty-nine plans or schemes for the embankment of the Thames. The commissioners recommended the postponement of the southern embankment: they concocted a plan among themselves from the other fifty-nine, and they recommended that it should be carried out by a distinct commission appointed for that purpose. Mr. Thwaites, chairman of the Metropolitan Board of Works, differed from the other commissioners chiefly on this point—that he wished the embankment to be constructed by his own board, which already had the management of the main drainage.

At length, in 1862, an Act was passed for a northern embankment, after a report from *another* committee that filled 360 folio pages. The Act is the 24th and 25th Vict., c. 93. By this statute there will be an embankment from Westminster to Blackfriars. The public roadway on this embankment will be 100 ft. wide from Westminster Bridge to the eastern boundary of the Inner Temple, and 70 ft. wide from the last-

named point to Blackfriars Bridge. Approach roads, 40 ft. at least in width, are to lead from Surrey Street, Norfolk Street, and Arundel Street to the embankment. There is to be another approach road, extending diagonally from Wellington Street, Strand, to the embankment near Charing Cross railway bridge, with short branches to Villiers Street and Buckingham Street; and other approach roads, with good access to the embankment, from the Adelphi, from Whitehall, and from Whitehall Yard. There are to be no docks behind the embankment—the space is to be filled in and reclaimed. The Act only marks out the general features of the plan; the Metropolitan Board of Works were to settle the details. The property is to be purchased by 1867, but the execution of the work is not limited to that period. The line of embankment is so chosen as to form a continuation of the terrace in front of the Houses of Parliament. The distance to which it will extend out into the river (at high water) is 220 ft. opposite Richmond Terrace, 400 ft. opposite Scotland Yard, 300 ft. at Charing Cross, 450 ft. opposite Buckingham Street, 300 ft. opposite Salisbury Street, and 130 ft. opposite Somerset House. The first brick pier of Charing Cross Bridge and the first pier of Waterloo Bridge will nearly denote the distances from the shore at those spots. The embankment will be solid so far only as the Temple Gardens; eastward of that point it will rest on columns, and will leave space for barge-traffic behind it. Mr. Bazalgette finds that he has to carry the foundations 30 ft. below the bed of the river. He sinks iron caissons, fills them with concrete and brickwork, and raises upon them (from below the level of low-water) a solid granite-faced embankment. The low-level sewer will be constructed behind and under the protection of the embankment wall.

Throughout the various negotiations concerning the embanking of the north side of the river, the inhabitants on the south bank strongly urged the embanking of that also; and in reference to very pressing requests, the Government oppointed a commission, in 1862, to inquire into the matter. After examining about twenty plans, the commissioners, while admitting the improvement which the Thames would experience by being embanked on the south side, from Westminster Bridge to Deptford, did not feel justified in recommending, at present, such an extensive work. They proposed, however, an embankment for the distance between Westminster Bridge and Battersea Park. This embanked roadway would be about 4½ ft. above Trinity high-water mark, 70 ft. wide, and 2 miles long. It would be an ornamental viaduct opposite the Houses of Parliament, as far as Bishop's Walk; then a solid embankment as far as the London Gas Works; then on arches to Nine Elms; and then solid to Battersea Park. They further recommended the dredging of this portion of the bed of the river to a level of 5 ft. below low-water mark.

The session of 1863 witnessed the passing of an Act for this Southern Embankment. The Metropolitan Board of Works are empowered to form an embankment from Gunhouse Alley to Westminster Bridge; to enlarge the bed of the river along a portion of this distance; to connect the embankment, by approach roads, with Palace New Road, and Vauxhall Row; to reclaim the portion of foreshore behind the embankment; and to make a public footway 20 ft. wide on the embankment. It will thus be seen that this scheme is a very limited one—a first instalment of what may be a large undertaking in the course of time.

The fire-places, great furnaces, and factory stoves of London are to pay for both embankments, in the form of coal dues.

APPENDIX No. 5.

REPORT (MADE, BY ORDER, TO THE COMMISSIONERS OF SEWERS), UPON THE MOST ADVANTAGEOUS MODE OF DEALING WITH THE SEWAGE MATTER OF THE METROPOLIS, WITH A VIEW TO THE PREPARATION OF SEWAGE MANURE, BY THOMAS WICKSTEED, ESQ., CIVIL ENGINEER.

From this interesting Report (dated February 13, 1854), we present our readers with the following extracts which describe the works conducted at Leicester by Mr. Wickstead, and the results he has obtained in a successful deodorisation and disinfecting of sewer water.

"In 1845 I was called upon by the projectors of the London Sewage Company to report to them upon the practicability of carrying out a scheme for distributing the sewage water of London in agricultural districts by the application of steam power and pipes, and was further instructed, that if I found it could not be carried out thus so as to prove profitable, to suggest, if possible, some other mode for effecting the object; and it was at that period that I entered into the calculations as to the cost of such a scheme, which led me to form the opinion that it could never be made a remunerative speculation. I then considered a scheme for arresting the fertilising matter held in suspension in sewer water, and found that even had it been as valuable as the matter held in solution (which is by no means the case), the quantity to be obtained, having regard to its quality, was too small to be remunerative.

"It then occurred to me, that if by a mode much less costly than *that of evaporation* to dryness, a sufficient quantity of the fertilising *matter held in solution* could be separated, that the collection and ex-

traction of fertilising matter from sewer water, might *then* be effected at a remunerative cost, or otherwise the scheme must be abandoned.

"I then consulted my friend, Mr. Arthur Aikin, the eminent chemist, at that time Professor of Chemistry at Guy's Hospital, as to whether there was any cheap substance that could be employed to separate the fertilising matter dissolved in sewer water, and which would not itself prove injurious to the manure; and he informed me, that he had for forty years previously been in the habit of using a small quantity of lime to separate the organic matter contained in the New River water, which application had always effected its intended purpose, and that he had no doubt it might be applied with good effect to the sewer water. Mr. Aikin tried some experiments upon the London sewage water, and found, that, by the addition of about the three-thousandth part by weight of lime, the quantity of precipitate obtained was double of that which had previously resulted from the precipitation of the solid matter only, held by mechanical suspension in the sewer water. The result of these experiments showing, that not only was the weight of the manure to be obtained doubled, but that the addition being much more valuable as a fertiliser, the whole quantity was rendered superior, and it appeared to be very probable that a remunerative scheme might be formed; accordingly I designed a plan for the projectors of the London Sewage Company, and plans were prepared and deposited for parliament, and the same was done in the following year, but at neither of the periods could the company proceed for want of the necessary capital.

"For some time after that period the state of the money market was such, that although various similar schemes were published for tunnel sewers with artificial falls, I considered my scheme would not be much advanced by bringing it in opposition to the new schemes until there was a greater chance of being able to raise capital for its execution.

"About the year 1849, I consulted my friend Mr. Robert Stephenson upon the subject, who was kind enough to enter into a thorough investigation of my scheme and an examination of the data upon which it was founded. He afterwards expressed a favourable opinion of its feasibility; the objections to it he considered to be chiefly the large size of the reservoirs, which we agreed it would be desirable to reduce if a scheme for so doing could be devised. And as to the question of the tunnel sewer itself being constructed by a private company, instead of by a public commission,—as it is clear that the company's interest would be to make the sewer as little in excess of the size required to convey the sewer water when sufficiently impregnated with fertilising matter to render its extraction remunerative, while a

commission, not being swayed by such considerations, would naturally consider the question of getting rid of flood waters also,—he thought, therefore, that it would be better, if possible, to divide the scheme, leaving the sewer to the public commission, and the process of disinfecting and utilising the sewage water to a company. Thus encouraged, I proceeded farther in the consideration of the subject, and in the following year the idea of applying centrifugal force for the separation of the water from the deposit in the bottom of the reservoirs suggested itself to me, and, having tried the effect practically, in 1851 I took out a patent for the manufacture of sewage manure.

"The result of experiments with the patent process was to show, that, by its adoption, the size of the reservoirs might be greatly reduced; that the deposit from the bottom of the reservoir might be abstracted without exposing it by the removal of the supernatant water; and that it might be rapidly reduced into a sufficiently solid state to admit of its being packed in casks, stored in pits or heaps, or moulded into bricks for the purpose of farther drying by natural evaporation. In the latter part of 1851, Mr. Robert Stephenson, and Professors Aikin and Taylor, having expressed very favourable opinions of the practicability of my amended scheme, which opinion they allowed me to publish, parties were thereby induced to purchase my patents for Great Britain and Ireland, and in 1852 an Act of Parliament was obtained, incorporating the "Patent Solid Sewage Manure Company," and enabling the Company to raise capital to the extent of 100,000*l.*

"In February, 1852, the Directors resolved that temporary works should be erected in Leicester for the purpose of manufacturing the manure upon a sufficiently large and practical scale, having in view three objects:—the first being to ascertain whether the lime process effectually disinfected the sewer water, and if so, whether it could be practically used upon the large scale; the second, to ascertain whether the removal of the precipitate from the bottom of the reservoir, and the abstraction of the water from it by means of centrifugal force, could be practically carried out upon the large scale and at a sufficiently small cost; the third object being, to manufacture a sufficient quantity of the manure to enable agriculturists to prove its commercial value, considering that their practical opinions would be a much better test than chemical analyses only, and it was resolved that upon the result of these trials, the question of proceeding with the Company should be decided. Works were accordingly erected, and after many alterations and improvements upon the original scheme, which probably would not have suggested themselves unless the opportunity of carrying the plan out practically had been afforded, the Directors were so satisfied with the result, that they felt justified in entering

into a contract with the Town Council of Leicester, undertaking in return for the exclusive right to all the sewage water for a period of thirty years, to disinfect it, and discharge the water in an innoxious state into the river Soar for the same period.

"The estimated cost of the necessary works is 25,000*l.*, and contracts were entered into in April last, for the erection and completion of them in last October, but owing to unfortunate and unforeseen circumstances,—first, to the delay in obtaining the land; secondly, to the unparalleled wet season which has peculiarly affected these works, the site of them being on low marsh ground; and, thirdly, to the great difficulty in obtaining labour, owing to the strikes amongst the workmen, and the delay in obtaining materials,—I am afraid these works, which, under ordinary circumstances, might easily have been completed in five months, will not be in effective operation much, if at all, before next summer.

"I will now proceed to describe the temporary works and the process, to the maturing of which I have devoted the greatest portion of my time for the last two years, and have completely satisfied myself that the scheme is not only practicable and remunerative, but may be made very profitable when carried out on a larger scale than opportunity has hitherto afforded.

"The temporary works at Leicester were erected upon ground belonging to the Town Council, upon the banks of the Leicester Navigation, near the outfall of the filthiest sewer in the town, a branch from which supplied the works with sewer water. The use of the ground was granted to the Company, at a merely nominal rate, by the Town Council, who in this, as in other instances, have afforded every facility to enable the Company to demonstrate to the public the practicability of disinfecting the water and manufacturing the manure.

"As regards the size of the temporary works, they were calculated for a population of 5,000, previous to the introduction of a supply of water into the town from the New Water Works. I do not mean to imply that we have actually deodorised the sewer water from a population of 5,000 during twelve months. for this would be inaccurate, as the constant interruption arising from the practical modifications and improvements of the machinery used in the process would of itself have prevented such a course; but the works have for different periods been kept in continuous operation day and night, that I might have the opportunity of assuring myself that the process was complete as affecting the sewer water during any of those periods, the object of these temporary works being, as I have before stated, to ascertain whether the process could be practically and remuneratively carried out by the means proposed.

"At the commencement of our operations, it was found that the

process of deodorising was not perfect, and it was discovered that its partial failure was due to the sewage water being in too concentrated a condition, the new supply of water to the town having only been introduced at Christmas last, while the operations of the Company commenced more thau a year and a half ago. To prove whether this conjecture was correct, a portion of the partially deodorized water was returned into the engine well, and when the concentrated sewage was reduced to a quality equal in strength to that of the metropolitan sewer water, the process was completely successful.

"Professors Aikin and Taylor ascertained the strength of the London sewer water, and determined what amount of dilution was necessary to reduce the Leicester sewer water to the requisite strength, and by their experiments I was guided in my practical operations.

"Again, it was found that at night, when the manufactories were not at work, and the waste water from the engines had ceased to flow into the sewer, their contents being chiefly urine and excrementitious matter in a state of far greater concentration than the day sewage, the effect of the lime was only partial, but upon diluting it as in the former case, the process of deodorising was completely successful—the effluent water from the reservoir, after the process was completed, being perfectly free from all taste and odour, excepting occasionally from the lime when it had been used in excess.

"A quantity of the effluent water from the reservoir was taken in August last, by Mr. Theodore West, chemist, of Leeds, and subjected to an analysis, and he found that there was not a trace of any other matter than carbonate of lime, sulphate of lime, and chloride of sodium, proving clearly that all noxious matter had been abstracted during the process.

"The mode of operation in this process is as follows:—the water is pumped up from the sewer, and into the pipe conveying it to the reservoir a smaller pipe is introduced, connected with the lime-pump, which works stroke for stroke with the sewer water-pump, and the process of deodorising is so rapid that when the mixture of sewer water and lime is discharged into the reservoir, there is no noxious odour arising from it; the discharge takes place into the first part of the reservoir divided into three compartments, in each of which is an agitator worked by the engine: a thorough mixture having thus been effected, it flows through the upper end of the reservoir, and is from thirty to forty minutes passing through this portion, during which time seven-eighths or more of the separated matter has been precipitated on the bottom of the reservoir; there still remains, however, about one-eighth of solid matter, and which being lighter than the first portion, requires a longer time for precipitation, so as to render the water clear and bright.

"The water is, in fact, two hours in passing from the sewer to the farthest end of the reservoir, where it is discharged, and arrangements are made to enable the water to flow continuously through the reservoir with as nearly as practicable the same velocity over the whole section, the openings of the discharging gates being proportioned to the depth of water in the cross section, and thus the necessity of having two reservoirs, for the purpose of filling one while the water in the other is being cleared by deposition, is avoided, for although the stream is continuous, its velocity being only about one-fourth of an inch per second, it does not interfere with, or arrest the precipitation of the solid matter.

"The operation of removing the precipitate from the bottom of the reservoir, so as not to interfere with the continuous flow of the water in the reservoir, is performed by means of a screw, which removes the precipitated matter into an adjoining well or shaft as rapidly as it is formed, without disturbing the process of precipitation which is carried on above it.

"The bottom of the first portion of the reservoir is made to slope towards the centre, along which a culvert runs, semi-circular at bottom and open at top; in the bottom of this the screw is laid, and the precipitate collecting upon it from the sloping sides, is, as the screw revolves, carried into the adjoining well: the practical working of this arrangement is now completely successful.

"It is the combination of these two arrangements; viz., the continuous current and the removal of the deposit without disturbing the supernatant water—that has enabled me to reduce the size of the reservoirs to so great an extent: this will be seen hereinafter when I give the sizes of the reservoirs I propose for the metropolis.

"The next operation is to raise the deposit or mud from the well or shaft, by means of a Jacob's ladder, very similar in appearance and construction to the ladder of buckets in the dredging machines used on the Thames, excepting that its position is vertical and its construction much slighter; the mud thus raised in a semi-fluid state into a tank, flows through a pipe to the centrifugal machine, the machine is then set in motion at the rate of about 1,000 revolutions per minute, and in half an hour from the time the precipitate lay on the bottom of the reservoir, it is in a sufficiently dry state to pack in casks or to mould in the form of bricks for farther drying.

"A given bulk of the manure, when introduced into the centrifugal machine, is reduced to about one-third of its original bulk, two-thirds, as water, having been separated from it by the operation.

"The machines which are now making for the new Leicester Sewage Works, are each calculated to turn out 360 lbs. of manure in an hour, in the state of consistency previously mentioned.

"Thus it will be seen, that the whole operation of disinfection and

conversion into manure is very simple, and I think it must appear evident, that after the experience of a year and a half of what may be done in works sufficient for a population of 5,000, that by simple multiplication of the means, it may be made available for any population, however great; as in this case the increased quantity of sewage water merely involves a simple increase of machinery in proportion to this increase, the increase of power for raising it being in direct proportion to the quantity.

"There is one very important conclusion that may be drawn from what has been said; viz., that an increased supply of water, by which means only the greatest and most immediate sanitary effect will be produced upon the atmosphere of dwellings in any town, does not render the plan just described abortive, on account of the enormously increased expense; but, on the contrary, within certain limits, the more the sewage is diluted, the more complete is the effect of the disinfection of the water and the precipitation of the manure, so that the sanitary objects of the Commissioners and the commercial interests of a Company carrying on the works, would not be opposed to each other as would be the case in the event of the liquid scheme being adopted.

"In the temporary works at Leicester, although the reservoir, the steam-engine and boiler, the machinery for manufacturing the manure, and the store for the manure, whether in casks or exposed in heaps for drying, are under one roof, no noxious effect has in the slightest degree been caused to the workmen employed in the process; and although the manure itself, when taken from the cask and held to the nose has a smell which an agriculturist would not object to, nevertheless, no smell whatever is perceptible at the distance of a foot or two from the manure.

"As regards, however, the proposed large works for Leicester, there will be two reservoirs, about 200 feet long, and 44 feet wide, two-thirds of the area will be covered with an iron girder and brick arch floor for the warehouses above, to economise space, and the whole will be roofed over; and as this portion of the design is intended to be carried out in all future works, however large, all chance of nuisance from exposure is avoided; but the fact is completely established, that no nuisance does arise either from the reservoirs or in the process used in manufacturing.

"Upon this point, and in corroboration of my statements, I beg leave to call your attention to the practical evidence of his Grace the Duke of Rutland, given in a letter I had the honour of receiving from him; also of Joseph Whetstone, Esq., the Chairman of the Local Board of Health; John Ellis, Esq., late M.P. for Leicester, the Town Clerk; Dr. Shaw, and other medical gentlemen of the town of *Leicester*, given in a certificate, which, with another from John Buck,

Esq., late Medical Officer of the Leicester Local Board of Health, who has had frequent opportunities of witnessing the operation of the patent process, are addressed to your Honourable Board, as I thought it might be more satisfactory to you to have the evidence of disinterested parties.

"Although not in a position at present to state what the 'actual commercial value of the residual manure will be, because, as before intimated, the desire of the directors of the Patent Solid Sewage Manure Company has been to leave this to be determined by the result of its practical application by the agriculturist, and at present the manure that has been so applied has been *pro tanto* inferior to what is intended to be supplied, in its having been chiefly collected from the day sewage unmixed with the richer night sewage, and also from the fact of its containing 60 or 70 per cent. of water instead of 20 per cent., which is the quantity it would have contained, if the extent of our temporary works had afforded us room for drying it in larger quantities than has hitherto been practicable; nevertheless, our experience has been quite sufficient to prove that, without the necessity of having recourse to expensive applications of artificial heat, simple exposure to atmospheric influence for a few weeks will reduce the moisture to 20 per cent., so that, bulk for bulk, the manure intended for sale will contain twice as much fertilising matter as that which has at present been forwarded to agriculturists for trial. The present results, however, show that, taking guano at 10*l*. per ton, the manure, as proposed for sale, is at least worth 2*l*. 13*s*. per ton; but as I stated to the Commissioners verbally, I have considered it safest to calculate its commercial value at 2*l*. or 2*l*. 2*s*. per ton, and this amount would yield, after deducting the cost of manufacture and repairs, a fair per centage upon the capital expended in the construction of the works; but the actual value will not be ascertained until time has afforded more extensive experience. But while it is undoubtedly of importance that the Commissioners should be satisfied that it is of sufficient value to induce capitalists to subscribe for its manufacture, its real value, if greater, must depend in some measure upon the favourable locality of the works—in relation to the agricultural districts—and hence its concentration, by reducing the cost of carriage, will increase its value, weight for weight; and again, the reduction in the cost of manufacture, which the last year's experience has already enabled me to effect, has also shown, that, with larger opportunities, further reductions may be effected, which, I need not remind the Commissioners, has generally been the case in all new manufactures.

"The cost of manufacture will be proportionably greater in small works than in larger ones: my present experience, however, enables me to state, that, upon the average, the cost of manufacture will not exceed 20*s*. per ton."

As to the application of his treatment to the sewage of the metropolis, Mr. Wicksteed had been supplied by Mr. Bazalgette, engineer to the Metropolitan Commission, with a map and the following particulars:—

"The main sewers of the Eastern Division are capable of being terminated at the points A, B, and D, at the river Lea, and their contents being separately or collectively manufactured into manure in that locality, or they can be continued so as to discharge at mean high water at the mouth of the Roding. With this view, A and B will be 9 feet above Trinity high water at crossing over the river Lea, and the sewage could possibly be there converted into manure without pumping.

"The main sewers of the Western Division will have two separate flood outlets into the river at the points E and I, the inverts being there level with low water.

"Sewage manure works could be established at both those points, or the sewers could be so connected as to have one establishment.

"We have taken the sewage at 5 cubic feet per head, and the tables give the sewage thus due to the present population, and also due to the ultimate increase of population as estimated by us.

NORTHERN SEWAGE INTERCEPTION AND DRAINAGE.

		Present Population.		Prospective Population.	
		Cubic Feet per Diem.	Cubic Feet per Minute.	Cubic Feet per Diem.	Cubic Feet per Minute.
Hackney Brook . .	A	462,240	321	2,075,040	1,441
Middle Level . . .	B	3,911,040	2,716	4,574,880	3,177
Low Level . . .	C	3,225,600	2,240	3,415,680	2,372
Total . .	D	7,598,880	5,277	10,065,600	6,990

WESTERN DIVISION.

Acton Line . .	F	169,920	118	662,400	460
Cheyne Walk Branch to ditto	F	224,640	156	224,640	156
Brentford Line . .	G	298,080	207	1,732,320	1,203
Fulham Branch to do.	H	37,440	26	139,680	97
Total . . .	I	730,080	507	2,759,040	1,916

"MEMORANDA.—The height of the lift, from the invert of the low level sewer at the pumping station near West Ham Abbey, to the invert of the high level sewer, is 35 feet, and to Trinity high water mark, 26 feet. The height of the lift, from the invert of the sewer at the pumping station in Fulham Meadows to Trinity high water mark, is 17½ feet."

Mr. Wicksteed's estimate for works required for treating the sewage of the metropolis, according to this arrangement of main sewers was as follows:—

PROPOSED WORKS.

"Without giving an opinion as to the actual sites that should be secured by the Commissioners, which I have no doubt you will agree with me would be premature, not to say imprudent, and in the choice of which I have no doubt you will be much influenced by your Engineers, to whom I shall be happy to give my assistance if required,—I may state, that it appears to me that four sites at least should be obtained for the proposed works: the first in the neighbourhood of the River Lea, uniting A and B, or the Hackney and the middle levels of the northern division; the second, in the neighbourhood of the same river, to receive C, or the low level of the northern division; the third, in the neighbourhood marked I, upon the plans supplied to me by your Engineer, uniting the Acton, Cheyne Walk, Brentford, and Fulham levels of the Western Division; and the fourth, on the banks of the Thames, on the south side of the river, for the southern sewage.

"Supposing, in other respects, these sites to be eligible, there could be no objection to them on the part of the Patent Solid Sewage Manure Company; but to repeat what I have hereinbefore intimated, there is nothing as regards the disinfecting and manufacturing of the manure to prevent either a concentration of, or a further subdivision of manufactories; and if, therefore, it should appear hereafter that a different arrangement would lead to a reduction in the size and cost of the main sewers, or for causes at present not foreseen an alteration should be deemed advisable, I see no objection to its being made. However, this part of the subject does not appear to me to press in such a manner as to lead to the necessity of my delaying the completion of this Report; should, however, the sites herein suggested be finally determined upon by the Commissioners, the following statement will represent the principal works that would be required for each:—

I.—THE QUANTITY OF LAND REQUIRED FOR ALL PURPOSES, No. 1, AND FOR RESERVOIRS, No. 2, INCLUDED IN No. 1.

	Present Population.		Prospective Population.	
	No. 1. Land for all Purposes.	No. 2. Land for Reservoirs.	No. 1. Land for all Purposes.	No. 2. Land for Reservoirs.
	Acres.	Acres.	Acres.	Acres.
1st Site . .	$8\frac{1}{2}$	$2\frac{3}{4}$	$12\frac{1}{2}$	$4\frac{1}{4}$
2nd Site . .	6	2	$6\frac{1}{2}$	$2\frac{1}{4}$
3rd Site . .	$1\frac{1}{2}$	$\frac{1}{2}$	$5\frac{1}{4}$	$1\frac{3}{4}$
4th Site . .	$5\frac{3}{4}$	2	7	$2\frac{1}{4}$
Total . .	$21\frac{3}{4}$	$7\frac{1}{4}$	$31\frac{1}{4}$	$10\frac{1}{2}$

II.—FULL AND AVERAGE POWER OF PUMPING ENGINES AND COALS.

	Full Power.	Average Power.	Coals per Annum.	Full Power.	Average Power.	Coals per Annum.
	H. P.	H. P.	Tons.	H. P.	H. P.	Tons.
1st Site . .	Nil	Nil	Nil	Nil	Nil	Nil
2nd Site . .	223	$148\frac{1}{2}$	1545	236	157	1635
3rd Site . .	$37\frac{1}{2}$	25	342	$141\frac{1}{2}$	$94\frac{1}{3}$	981
4th Site . .	225	150	1560	270	180	1872
Total . .	$485\frac{1}{2}$	$323\frac{1}{2}$	3447	$647\frac{1}{2}$	$431\frac{1}{3}$	4488

"With the exception of the land and approaches, the above works would have to be provided and maintained by the Company, and in addition the Company would have to provide for manufacturing purposes—

Engine-power for present population	2,955	horses' power
Ditto for prospective ditto	4,286	„ „
Coals, per annum, for present ditto	26,341	tons
Ditto, ditto, for prospective ditto	38,205	„

"To show the importance of having manufactories established on sites accessible for carriage, I may state, that the probable present and prospective annual tonnage of coals, lime, and manure, will be as follows:—

	Tons.
For present population	214,000 per annum
For prospective ditto	310,000 „

"The capital required for the construction of works for the *prospective population* would not exceed 1,000,000*l*. sterling."

APPENDIX No. 6.

Projects for Utilising Sewage, 1854 to 1865.

In relation to the *Main Drainage* of the metropolis, we have been able, in a former number of the Appendix, to describe a very important advance made since the publication of the second edition of this work in 1854. The *Sewage Manure* question, however, has not been so fortunate. We are still, in 1865, as we were in 1854, groping in search of a practical, if not profitable plan. Boards, committees, commissions, inspectors, and civil engineers, all have been examining and reporting; and the following brief account will show in what direction speculative ingenuity has sought for a solution of this very difficult question. For fuller details we refer to Mr. Scott Burn's Rudimentary Treatise noticed in the Preface.

In 1856 the Board of Health directed their chief superintending inspector, Mr. Henry Austin, to prepare a "Report on the Means of Deodorising and Utilising the Sewage of Towns." In 1857 that report was presented, consisting of about a hundred pages of text, and seven lithographed plans. Mr. Austin entered very fully into the chemical and agricultural relations of sewage manure, the (then) existing arrangements concerning the drainage of towns, the deodorisation of sewage, and its manufacture into solid manure. He treated the general principles of the subject, so far as they have yet been determined; and obtained evidence from various quarters as to the facts. He described various *chemical* processes for separating the solid matter of sewage, as patented or suggested by Mr. Higgs, Mr. Wicksteed, Mr. Stothert, Mr. Herapath, Mr. Dover, Dr. Angus Smith, Mr. Blackwell, Mr. Manning, and Mr. McDougall. He next similarly examined various *mechanical* processes for effecting the same end, as adopted with more or less success at Cheltenham, Uxbridge, Ely, Hitchin, and Dartmoor Prison. Mr. Austin then instituted inquiries into the utilisation of sewage in the liquid form, by *open irrigation* and by *underground pipes:* and into the relative advantages of town sewage and farm-yard manure for agricultural purposes. Mr. Austin wound up his report with a series of "Conclusions," the most practical of which were as follow:—

"That in order to avoid all further risk of injury to health, whether from discharge of the sewage into the rivers and streams, or from its application to the land, it appears desirable that the solid matter should in every case be separated from the liquid sewage at the outfall, and that a cheap portable manure should be manufactured therefrom for use in the immediate neighbourhood.

"That it should be mixed with the ashes of the town, or such other deodorising material as may be most suitable for application to the surrounding land, and prepared, if desirable, with other manuring ingredients for particular crops.

"That it appears probable that such operation will in most places pay its own expenses; but that, as some such measure is absolutely necessary for the public health, even though involving some expense, it should be the duty of local boards and other governing bodies to carry it out, just as much as arrangements devolving upon them for removal of dust or other refuse from the town. It should form, in fact, part of such service, and might be combined in the same contract.

"That the liquid portion of the sewage, thus cleared of its solid matter, but still retaining its chief value as manure, might then be applied with benefit to the neighbouring lands in any quantity; but that all land upon which this method of application of the sewage is practised should, if not naturally porous, be artificially drained, as the liquid, if allowed to become stagnant, would, as in common irrigation, be likely to engender disease in the neighbouring inhabitants, or in cattle exposed to its influence.

"That the distribution of manures in the liquid state by the hose and jet, from a system of underground pipes on the land, has been found, by the experience of several years upon farms in England and Scotland, most advantageous; and that the outlay for such works is considered by eminent agriculturists, who have had experience of their benefits, as a very profitable outlay, irrespective altogether of the question of sewage distribution.

"That upon grass lands, for which the application is best adapted, these larger quantities of the liquid sewage, deprived of its grosser particles, may be economically distributed, especially upon the lower levels, by a combination of the underground pipe system with the subsidiary open irrigation by small contour gutters.

"That the solid sewage manure, prepared and deodorised as above proposed, may be used anywhere, and any quantity of the liquid applied on absorbent or properly drained land, without any risk of injury to health, and without any of the offensiveness constantly experienced from farmyard and other solid manures applied as top-dressings.

"That in any neighbourhoods, however, where no opportunity exists for this beneficial irrigation, the liquid sewage, before being discharged into rivers or streams, should, after separation of the solid matter, be treated with lime or other deodorising and precipitating agents—a duty which should devolve upon the local board or other governing body, as a precaution in which the public health is materially concerned."

Such was the substance of Mr. Austin's recommendation. It has been *a misfortune*, in relation to this matter, that the same facts are described

over and over again, and printed in the Blue Books at the public expense, by rival or independent boards, commissions, and committees. Instead of acting upon any of the suggestions made to the Board of Health by Mr. Austin, a new body proceeded to investigate the whole matter over again. In 1857 a *Sewage Commission* was appointed, consisting of Lord Portman, Dr. Southwood Smith, Mr. I. K. Brunel, Mr. H. K. Seymer, Mr. Rawlinson, Professor Way, Mr. Lawes, Mr. Simon, and Mr. Austin. Their duties were "to inquire into the best modes of distributing the sewage of towns, and applying it to beneficial and profitable uses." The commissioners appointed five of their number as a committee "to visit and personally examine the different localities where sewage is employed in agriculture, or treated with a view of neutralising its offensive and noxious properties;" leaving for a subsequent period in their labours, "to undertake a series of distinct experiments to test the efficacy of existing methods, and, if possible, to improve upon them." The localities visited by the committee in which sewage was applied to the land in a liquid form were Rugby, Watford, Edinburgh, Rusholme, Mansfield, and Milan; those in which works were in operation for the purification of sewage were Croydon, Leicester, Tottenham, and Cheltenham. The committee also visited several farms, in which farm-yard liquid manure was used on a large scale; the farms selected being the Earl of Essex's, at Cashiobury; Mr. Mechi's, at Tiptree; Mr. Wheble's, at Bulmarsh Court; Mr. Kennedy's, at Myer Mill; Mr. Telfer's, at Cumming Park; the Marquis of Breadalbane's, near Luing; and Mr. Hervey's, near Glasgow. The general report of the commission, founded upon the special reports of the committee, and sent in to the Treasury in 1858, was necessarily little more than a repetition of Mr. Austin's statements, extending over nearly the same area, and arrived at nearly in the same way. It will suffice to give merely a few of the results at which the commission arrived:—

"That the methods which have been adopted with the view of dealing with sewage are of two kinds—the one being the application of the whole sewage to land; and the other that of treating it by chemical processes to separate its most offensive portions.

"That the direct application of sewage to land favourably situated, if judiciously carried out, and confined to a suitable area exclusively grass, is profitable to persons so employing it; and that, where the conditions are unfavourable, a small payment on the part of the local authorities will restore the balance.

"That this method of sewage application, conducted with moderate care, is not productive of nuisance or injury to health.

"That when circumstances prevent the disposal of sewage by direct application to land, the processes of precipitation will greatly ameliorate, and practically obviate, the evils of sewage outfalls, especially where

there are large rivers for the discharge of the liquid; but that such methods of treating sewage do not retain more than a comparatively small portion of the fertilising matters; and that, although in some cases the sale of the manure may repay the cost of production, they are not likely to be successful as private speculations.

"That, considered merely as the means of mitigating a nuisance, these precipitating processes are satisfactory; that the cost of them in any case is such as town populations may reasonably be called upon to meet; that the necessary works need not, if properly conducted, be a source of nuisance; and that, by modifications of the existing methods, even the slightest risk of nuisance may be entirely obviated.

"That the employment of the one or other method of disposing of sewage, or of both conjoined, must depend upon locality, levels, markets, and a variety of other circumstances; and that the case of each town must be considered upon its own peculiarities.

"That there is good ground for believing that the methods yet proposed for dealing with sewage are not the best that can be devised; and that further investigation will probably result in the discovery of processes more thoroughly equal to the suppression of the nuisance, and at the same time calculated to give more valuable products.

"That the magnitude of a town presents no real difficulty to the effectual treatment of its sewage, provided it be considered as a collection of smaller towns. As, however, the conditions under which the evil may be best removed will differ greatly in different localities, we think it would be desirable, before any legislation takes place on this subject, that investigation should be made into the state of the outfalls of different classes of towns, and of the condition of rivers in populous districts, with the view to advise as to the general legislative measures that might safely be adopted."

The commission also sketched a plan for dealing with the sewage of the metropolis, by combining an embankment of the Thames with a series of works for deodorising the sewage.

During the course of their labours from 1857 to 1863, the commissioners received numerous communications relating to plans for dealing with this difficult sewage question. Some proposed plans for the manufacture of "urban manure;" some for the disinfection of drains. Mr. Beadon had a plan for the drainage, collection, and deodorisation of the sewage of the metropolis by a system of subways, in which the sewage would be conveyed to suitable districts for the purpose. Mr. Bridges Adams proposed to collect separately the solid and liquid portions of the sewage, allow them to accumulate for a given time, and finally remove them for agricultural uses. Mr. Wright suggested a plan for producing an inoffensive solid manure by using burnt clay, charcoal, and gypsum,

with the sewage. Mr. Dover's suggestion was, so to employ hydrochloric acid, sulphate of iron, and common salt, as to separate the liquid from the solid portion of sewage, to render the former inodorous and inoffensive, and to manufacture the residium into a profitable, portable manure. Thirty or forty projects, more or less resembling those here noticed, were received and considered by the commissioners, but no definite course of action was adopted in reference to any of them. Two commissioners, acting as an agricultural committee, Professor Way and Mr. J. B. Lawes. have made many interesting experiments on fields near Rugby, by comparing the crops produced with and without the aid of sewage manure, Oxen were fed with grass grown on sewaged and on unsewaged land, and the fattening qualities of the two kinds were compared.

This Sewage Commission was appointed before there was a Metropolitan Board of Works, entrusted with the general drainage of the metropolis. Now, however, when there is such a board, the question is practically taken out of the hands of the commission, so far as London is concerned, seeing that it rests with the board to decide whether the sewage shall flow into the Thames, or whether the contents of the great reservoirs at Barking and Crossness shall be applied as manure. Nevertheless, the commission may still render service by encouraging plans that may be useful in other large towns.

The Report of the Metropolitan Board of Works, submitted at a meeting of the board held August 7th, 1863, emanated especially from the Main Drainage Committee, and related to tenders received from various persons for the sewage of the metropolis. Twelve parties had responded to an advertisement put forth by the committee, and the following, expressed in a condensed form, will suffice to show the nature of the tenders:—

1. Dr. Thudichum proposed by a mechanical arrangement so to separate the house-drainage as to retain that which he considered most valuable; and he gave a sketch of his closet and drains, and tables of analysis of the constituents of fluid sewage. He estimated the cost of the works for carrying out his process at 1,500,000*l.* Out of the net profit he proposed that he should receive a percentage, and that one half of the balance should be paid to the board, and one half to the shareholders of a company formed for carrying out the system.
2. Mr. Curwood was not in a position to offer a tender, but suggested the separation of the solid and liquid sewage.
3. Lord Torrington, Sir Charles Fox, and Mr. Hunt, while expressing their willingness to discuss a particular plan of theirs with the Main Drainage Committee, and to enter into a provisional arrangement for presenting a Bill in Parliament during the ensuing

session, regretted their inability to comply with the conditions of the advertisement, on the ground of the impolicy of publicly declaring the land with which they proposed to deal.

4. The London Sewage Utilisation Company (Limited) proposed that the board should grant them the sewage they might require at Barking Creek for two years, at a rent of £5; that, if the experiment succeeded, the board should then grant a further term of twenty-one years at the same rent; and that, at the end of such further term, the rent for a lengthened period should be referred for decision either to the Board of Trade or to the President of the Institute of Civil Engineers.
5. Mr. Moore proposed that the board should grant the sewage for a term of ninety years; that for fourteen years of this period the rent should be merely pepper-corn; and that for the remainder of the term, after deducting 10 per cent. on the capital invested, the rent should be one half of the profits. In a subsequent tender, made in July, 1863, Mr. Moore offered one farthing per ton for all the sewage raised by the board to a height of 200 ft.; at 80,000,000 gallons per day, this would amount to 136,000*l.* per annum. Mr. Moore stated that he had already engagements with the occupiers of nearly 60,000 acres for the use of the sewage. This plan of raising the sewage to so great a height seems to indicate some arrangement for allowing the liquid to flow by easy gradients to fields at a considerable distance.
6. Mr. Shepherd, as a first communication, asked for a concession of the whole of the sewage of London for fifty years. He proposed to establish a company to work the plan; and that, after this company had reached 7½ per cent. on the invested capital, he should share the surplus profits with the board. In a second communication, Mr. Shepherd stipulated more completely than before for an unlimited command over the whole of the sewage.
7. Mr. Kirkman's proposal embodied the use of a patent, of which he is proprietor, for obtaining manure from sewage by filtration and deposit; the water after such treatment to be discharged into the river. He proposed to erect works for this purpose at Barking, on condition that the board convey to him the necessary land adjoining the reservoir, deliver the sewage to him from the main outfall sewer into his works, grant him the use of their river frontage and wharves for the term of seven years at a pepper-corn, seven years at a rent of one-fifth the net profits, after deducting 5 per cent. on the capital, and for any further time at a rental to be settled by the Secretary of State. Mr. Kirkman stated that he was prepared to guarantee a minimum rent of 10,000*l.* per annum —*that* he could name two or more securities for the due perform-

ance of the contract, and that he would agree to the surrender of the works on two years' notice, subject to the repayment of the capital invested, and of a premium of 25 per cent. thereon, together with a royalty of 1*l.* per cent. for the use of his patent.

8. Mr. Ellis proposed to pump the sewage from the reservoirs at Barking and Crossness into certain covered tanks, and then to cause it to flow by gravitation through pipes laid along the sides of the roads adjoining the land to be irrigated. On behalf of a joint-stock company to be formed, Mr. Ellis undertook to provide and use deodorising agents. The net profits, after deducting working expenses and reserve fund, to be divided equally between the company and the board. The concession of the sewage to be in perpetuity, subject to the board's power of purchasing after fifty years, on giving three years' notice—the price to be fixed by valuers jointly chosen. Certain capitalists were prepared to back Mr. Ellis to the extent of 60,000*l.*

9. Messrs. Napier and Hope proposed to intercept the whole of the ordinary flow of the northern sewage near Abbey Mills, and to convey it by a culvert 44 miles in length to Maplin Sands on the one hand, and to Dengie Flats on the other. Both those areas are at present submerged at high water, and their redemption is part of the project, extending to 15,000 or 20,000 acres. The capital proposed to be invested was 2,000,000*l.*; the concession of the sewage to be for fifty years, subject to parliamentary authority being obtained, and to a grant of the land from the crown. The net profits to be divided equally between the company and the board, after deduction of 10 per cent. on the outlay. The board to have the power of resuming the grant of sewage, and taking the whole of the lands and works at a valuation, at the end of the term of fifty years, on giving seven years' notice; or a new concession to be granted in terms settled by the Secretary of State. The board to be represented by two directors appointed to the company. The company to be formed within two years after obtaining parliamentary powers. The company, within three months of its formation, to place in the hands of trustees a certain sum of money as security for the due fulfilment of the works.

The other three responses to the advertisement of the board did not take the form of tenders. It will suffice to show the difficulties which surround this subject to say that the committee did not feel justified in recommending *any* of the plans, and that it was resolved by the board that the committee's report, together with all the tenders, supplementary documents, and correspondence, should be printed, and copies sent to all the metropolitan vestries and district boards. From this it is pretty evident, that so far from any defined arrangement being made, the end

of the year 1863 witnessed merely the commencement of another series of plans, discussions, and controversies on this much-troubled sewage question. To detail the proceedings of 1864 would be little more than going again over the same ground; the controversies and proposals were numerous, but nothing definite resulted from them. In 1865, however, the Maplin Sand reclamation scheme is brought forward in a definite way, in connection with a system of sewage utilisation.

APPENDIX No. 7.

Water Supply of London, under the Act of 1852.

In addition to the information given in the text (p. 99), it may be desirable to present here a few facts concerning the supply of water to the metropolis, especially under the influence of the important statute passed in 1852. For the reason stated in the Preface, we may refer to Mr. Hughes' *Rudimentary Treatise*, for a fuller treatment of water supply generally.

In 1856 a valuable Report was presented to the General Board of Health, by the Superintending Inspectors of that Board (Messrs. Henry Austin, William Ranger, and Alfred Dickens), on the subject of the Water Supply of London. The Water companies having been required, by the terms of the Act of 1852, to make very extensive alterations and improvements in their works, it became desirable to ascertain how far the alterations had advanced. The inspector, therefore, made an exact comparison between the state of matters in 1850 and in 1856, before and after the Act of 1852 came into operation. The Act required that by August 31, 1855, no water should be taken by any of the companies (with one exception) from any part of the Thames below Teddington Lock; that all reservoirs within 5 miles of St. Paul's should be roofed in, unless the water is filtered after leaving the reservoir; that all the conduits or water channels within the metropolis should be covered, unless the water were filtered after leaving such channel. It may be useful to present here a few leading facts concerning the ten companies which supply the metropolis with water.

In 1850, there were 270,581 houses supplied with about 44,000,000 gallons of water daily, by nine companies; whereas in 1856 there were 328,561 houses supplied with 81,000,000 gallons per day, by ten companies: exhibiting a rise from 164 to 246 gallons per house per day. The main and branch pipes, irrespective of the private service pipes, were 2,086 miles in length, in 1856. There were 40 acres of filter beds, and 141 acres of subsiding reservoirs. The filtered water was stored in *fourteen covered* reservoirs, comprising an area of 15 acres, and in four

uncovered reservoirs, of about 3 acres, beyond the specified distance of 5 miles from St. Paul's. The cost of the several water-works, down to the enactment of the statute in 1852, was about 5,000,000*l.*; and a further sum of 2,300,000*l.* was spent between 1852 and 1856; to which an additional large sum has been added between 1856 and 1865.

The following are a few facts relating to each of the companies, individually, in 1856.

New River.—Sources of supply, New River, River Lea, and chalk springs. Number of houses supplied, 95,083. Gross quantity supplied per day, 25,000,000 gallons. Aggregate nominal steam-power for working the pumping and other engines, 1,442 horses. Length of mains and branches, about 450 miles. Area of subsiding reservoirs, 66 acres. Area of filter beds, 9 acres. Area of covered reservoirs for filtered water, 3¾ acres. Total cost of works, about 2,000,000*l.*

East London.—Source of supply, the River Lea. Number of houses supplied, 70,000. Gross quantity supplied per day, 16,000,000 gallons. Aggregate nominal steam-power, 840 horses. Length of mains and branches, 331 miles. Area of filter beds, 12 acres. Area of covered reservoirs for filtered water, 2½ acres. Total cost of works, 1,000,00C*l.*

Southwark and Vauxhall.—Source of supply, the River Thames, at Hampton. Number of houses supplied, 41,529. Gross quantity supplied per day, 10,330,000 gallons. Aggregate nominal steam-power, 1,065 horses. Length of mains and branches, 432 miles. Area of subsiding reservoirs, 8 acres. Area of filter beds, 4½ acres. Total cost of works, 650,000*l.*

Lambeth.—Source of supply, the River Thames, at Thames Ditton, Number of houses supplied, 28,541. Gross quantity supplied per day, 6,110,000 gallons. Aggregate nominal steam-power, 680 horses. Length of mains and branches, 206 miles. Area of filter beds, three-quarters of an acre. Area of open reservoirs for filtered water, 1¼ acre. Area of covered reservoirs for filtered water, 3 acres. Total cost of works, 610,000*l.*

West Middlesex.—Source of supply, the Thames, at Hampton. Number of houses supplied, 25,732. Gross quantity supplied per day, 6,900,000 gallons. Aggregate nominal steam-power, 480 horses. Length of mains and branches, 178 miles. Area of subsiding reservoirs, 16 acres. Area of filter beds, 4½ acres. Area of covered reservoirs for filtered water, 1¾ acre. Total cost of works, 800,000*l.*

Chelsea.—Source of supply, the Thames, at Seething Wells. Number of houses supplied, 25,030. Gross quantity supplied per day, 5,300,000 gallons. Aggregate nominal steam-power, 700 horses. Length o. mains and branches, 198 miles. Area of subsiding reservoirs, 3¼ acres. Area of filter beds, 2 acres. Area of covered reservoirs for filtered water, 2¼ acres. Total cost of works, 930,000*l.*

Grand Junction.—Source of supply, the Thames, at Hampton. Number of houses supplied, 17,221. Gross quantity supplied per day, 6,700,000. Aggregate nominal steam-power, 1,440 horses. Length of mains and branches, 117 miles. Area of subsiding reservoirs, 7¾ acres. Area of filter beds, 5¼ acres. Area of covered reservoirs for filtered water, a little over 1 acre. Total cost of works, 730,000*l.*

Kent.—Source of supply, the River Ravensbourne. Number of houses supplied, 16,077. Gross quantity supplied per day, 3,500,000 gallons. Average nominal steam-power, 500 horses. Length of mains and branches, 124 miles. Area of subsiding reservoirs, 5¼ acres. Area of filter beds, 2¾ acres. Area of open reservoirs for filtered water, 1½ acre. Total cost of works, 230,000*l.*

Hampstead.—Sources of supply, the Hampstead and Highgate Ponds, and an artesian well at Hampstead. Number of houses supplied, 6,348. Gross quantity supplied per day, 600,000 gallons. Aggregate nominal steam-power, 72 horses. Length of main and branches, 33 miles. Area of subsiding reservoirs, 35 acres. Area of filter beds, one-seventh of an acre. Total cost of works, 120,000*l.*

Plumstead and Woolwich.—Source of supply, an artesian well in the chalk. Number of houses supplied, about 3,000. Gross quantity supplied per day, 550,000 gallons. Aggregate nominal steam-power, 35 horses. Length of main and branches, 16 miles. Area of subsiding reservoirs, one-fifth of an acre. Area of covered reservoirs for filtered water, one-third of an acre. Total cost of works, 50,000*l.*

Some of the above-named companies were in 1856 without subsiding reservoirs, some without open reservoirs, and some without closed reservoirs; but very extensive additional works have been constructed between 1856 and 1865. Taking them one with another, the companies have spent about 20*l.* in works for each house supplied with water; and the interest on this amount, together with the annual working expenses, are considered in determining the annual water-rate charged upon each house.

At the Woolwich and Charlton works, established so recently as 1854, the water is softened by Dr. Clark's process, in which the chalk is rendered soluble; and the result, as stated by the inspectors to the Board of Health, is beneficial in regard to health, comfort, and economy. The inspectors made the following remarks on one still-existing source of impurity in the water supplied, notwithstanding the use of filter-beds and covered reservoirs:—"The only remaining serious cause of contamination will be the cisterns, water-butts, and other means for storing the supplies now furnished by the companies. Although considerable improvement has already taken place in the distribution, and the water formerly supplied only on alternate days is now for the most part given daily, except on Sundays, to every part of each company's district, its

storage even from day to day in the private butts and cisterns of most houses, and especially in those of the poorer class, to a great extent destroys the advantages that so much pains have been taken to secure. The only complete remedy for this serious defect will be the *constant supply*—that is to say, a supply obtained at all times by direct communication of the house-service pipes with the constantly-charged mains of the companies, thus avoiding the necessity for any means of storage whatever on the private premises. The constant supply would be the means of rectifying also another serious defect to which the public is not unfrequently liable in the present system—viz. the irregularities of supply. Notwithstanding that the companies have abundant means of furnishing any quantity of water that can be legitimately used throughout their districts, loud complaints are too often heard of a want of water in certain localities. The deficiency would appear to arise not from actual lack of water, but from some irregularity from time to time in 'districting' the service, which the constant supply would obviate. We would allude also to the great advantage of constantly-charged mains in case of fire as no small consideration."

The charge for water-rate by eight out of the ten companies (omitting the Kent and the Woolwich) for the year 1856, as given in one of the parliamentary papers, was as follows:—

New River	£156,367
East London	85,286
West Middlesex	72,165
Grand Junction	52,590
Chelsea	43,071
Southwark and Vauxhall	41,914
Lambeth	34,645
Hampstead	10,580

Taking an average of the whole, this gives a gross payment, by housekeepers and manufacturers, of about 1*s.* for 2,800 gallons of water, of 233 gallons for 1*d.*

We have no concern here with the controversy respecting the Trafalgar Square Fountains as matters of taste or art; but as they are connected in a small degree with the supply of the metropolis with water, a paragraph concerning them may not be out of place. The wells which supply the fountains also supply some of the government offices. In 1843 Messrs. Easton & Amos were employed to sink wells for this purpose to the level of the springs beneath the London clay. The fountains were not intended to be merely ornamental—they were to form cooling-ponds to condense the steam of the pumping-engines, the resistance of the air to the ascending jets producing a cooling action. The Government were encouraged to undertake this work by the ascertained fact that the

interest on the cost of the new works would be less than the water-rate paid by or for the government offices about the neighbourhood of Whitehall. The works were commenced on a piece of ground in Orange Street, behind the National Gallery. A well was sunk to the depth of 174 ft. A cast-iron pipe, 15 in. diameter, was then driven through 30 ft. of plastic clay, and 10 ft. into a stratum of gravel, sand, and stones. Within this another pipe of 7 in. diameter was driven through 35 ft. of green-coloured sand, and 3 ft. into the chalk. Boring was then continued to a depth of 300 ft. from the surface. The chief supply of water thence obtained came from the chalk. A second well was then sunk in the enclosure in front of the National Gallery, to a depth of 168 ft., and a pipe and a boring continued nearly as in the former instance, but to a depth of 383 ft. The springs were found to be stronger than those in the well in Orange Street. A tunnel, 6 ft. diameter, and about 400 ft. long, was driven to connect the two wells, at a depth of 123 ft. below Trinity high-water mark. The works were finished in December 1844, at a cost of 8,400*l*. The water rose to within 90 ft. of the surface, and was found to be of good quality. When the engine was pumping 110 gallons per minute, it lowered the water only 4 ft. in the well. In 1846, a further demand for water having arisen, a larger pump was substituted, capable of raising 350 gallons per minute. In 1849, another well was sunk in Orange Street, to a depth of 176 ft., and a tunnel was made to connect it with the others. The steam-engine works one double-acting pump for supplying the fountains, and two others for raising water from the springs into the tanks above the building. The pumping of 600 gallons per minute lowers the water 20 or 24 ft.; but then the level remains permanent, however long the pumping may be continued. In the beginning of 1859 the level of the water in the wells was found to be nearly as it had been throughout.

In a paper by Mr. P. W. Barlow, read before the Institution of Civil Engineers in 1855, the water-bearing strata of the London basin were described, with a view of showing how abundant is the supply of water available, if proper means were adopted for utilising it. This basin, defined by a boundary running through or near Folkestone, Hythe, Ashford, West Farleigh, Sevenoaks, Reigate, Godalming, Pewsey, Devizes, Swindon, Wantage, Tetworth, and Cambridge, covers an area of 8,000 square miles; and the water-bearing strata beneath this area comprise the London clay, the chalk, the upper greensand, and the lower greensand. The superficial area through which rain infiltrates west of London, and from which the supply for the artesian wells of London is obtained, is about 24 square miles. About 200 square miles of area eastward of London, where the lower beds of clay are arenaceous and permeable, but where the upper or impervious beds are wanting, add very little to the supply of the ordinary London basin. Of the

3,800 square miles of chalk strata exposed to the surface, it is considered that this constitutes the great water-bearing stratum; and that, in parts where the chalk is 60 ft. or 80 ft. below the surface, there may be several supplies of water, irrespective of each other, at different depths, and applicable to different purposes. The district south-east of London was stated by Mr. Barlow to be peculiarly adapted for affording a water supply. Scarcely any of the springs in that part of Kent reappear in the form of surface springs; they mostly empty themselves into the Thames at low water, from fissures in the bed or banks. By intercepting these springs in their course towards the Thames, a copious supply of water might be obtained from the chalk. It was estimated that the drainage area of the water thus wasted is 190 square miles, west of the Medway, which might yield a daily supply of 60,000,000 gallons; and that 320 square miles, east of the Medway, might yield 100,000,000 gallons per day. Mr. Prestwich, from an investigation of the greensand, had arrived at a conclusion that those strata might be made to yield 40,000,000 gallons per day, which would probably rise to a height of 120 ft. above the surface; and he had suggested how desirable it would be, imitating the example furnished by the artesian well at Grenelle, if a similar experiment were tried in some spot of the London basin where the lower infiltrating springs would be intersected. Mr. Barlow quoted these speculations of Mr. Prestwich, and adduced his own experience as engineer of the South-Eastern and North Kent railways, to support the view that the metropolis ought not to be left mainly dependent on the Thames for its supply of water, seeing that that river is becoming more and more deficient, and that the strata of the London basin comprise so many beds that are water-bearing. A lengthened discussion took place after the reading of Mr. Barlow's paper, during which many engineers adverted to the uncertainties which have marked the sinking of deep wells near London. A well-known instance is the one on the road between Kentish Town and Highgate, sunk to obtain a supply auxiliary to that of the Hampstead Waterworks. The well was begun at a height of 172 ft. above Trinity high-water mark, with the hope of reaching water in the chalk at about 320 ft. below the surface. The chalk was compact, hard, free from fissures, and comparatively dry, with the flints not in layers, but distributed through the mass. After sinking 218 ft. in the chalk, boring was commenced, and continued to a depth of 1,150 ft. below the surface. After traversing 538 ft. of chalk, and then layers of gault and red clay, the greensand was reached; but so discouraging was the result, owing to the scanty indications of water, that the enterprise was regarded almost as hopeless. It was further continued, however, to a depth of 1,302 ft., and then abandoned, after two years and a half of labour, and a very heavy expense.

It does not seem very probable, now that the ten water companies

have invested such large sums in enlarging and improving the water supply of the metropolis, that any further radical changes will be made in this matter. But the future will have to settle the question. It is supposed that more than 50,000,000 gallons of water per day are at the present time (1865) taken out of the Thames near Hampton and Thames Ditton, in aid of the London supply; and it has still to be ascertained what effect that large draught will have on the general condition of the river. Hence such inquiries as those instituted by Mr. Prestwich and Mr. Barlow, and mentioned in the last paragraph, are important. We may notice, too, a project which bears relation to the chalk strata near Grays, in Essex, opposite Northfleet. In excavating the chalk for shipment, 2,000,000 gallons of water per day require to be pumped away into the river; and it has been proposed to utilise this water for the supply of towns, instead of thus allowing it to run to waste. Purfleet, Rainham, Brentwood, Dagenham, Ilford, Romford, Barking, East Ham, and other towns between Grays and London, might (it is conceived) be thus supplied. Messrs. Easton and Amos have estimated that, if 220,000*l.* were expended in the necessary works, a supply of 2,000,000 gallons every twelve hours might be obtained; 4,000,000 gallons by an expenditure of 268,000*l.*; and 6,000,000 gallons by an expenditure of 475,000*l.*

APPENDIX No. 8.

The Great Waterworks from Loch Katrine to Glasgow.

Without going into the subject of the water supply of our great towns generally, as developed between the years 1854 and 1865, we deem it desirable to notice those for the supply of Glasgow, unparalleled as they are in this country for engineering grandeur and public success.

The works were commenced in 1856, after lengthened inquiries in the preceding years. The old supply from the Clyde at Dumbarton had become quite inadequate. A plan had been proposed for bringing water from Loch Lubnaig, but had fallen to the ground. Loch Katrine was then named; and after a very favourable report from two distinguished engineers, since deceased, Mr. Brunel and Mr. Robert Stephenson, the corporation commenced that magnificent work which has become an honour to the city and to the engineer. The water comes from the mountain-lakes on the borders of Stirlingshire and Perthshire. The sources of supply are Loch Katrine, 8 or 9 miles long, with an area of 3,000 acres; Loch Vennachar, 4 miles long, with an area of 900 acres; and Loch Drumkie, with an area of about 150 acres. The three lakes would, if quite full, contain 1,600,000,000 cubic feet of water. The

basins which find their drainage into these lakes cover an area of 45,800 acres, and have an average rain-fall of about 80 in. per annum. The works at Loch Katrine are so managed that all the water for 4 ft. above the ordinary summer level, and 3 ft. below it, can be treated as a reservoir or store, with proper channels for drawing it off; this store is equal to 50,000,000 gallons per day for 120 days without rain. The water from Lochs Vennachar and Drumkie is chiefly appropriated to the supply of mill-owners, fishermen, and others interested in certain rivers; the supply for Glasgow being mainly obtained from Loch Katrine. At the outlets provision is made for the discharge of floods as well as for the daily regulated supply, and for securing the passage of salmon and other fish by properly constructed "salmon-ladders." Loch Katrine being 360 ft. above the river level at Glasgow, there is scope for a gentle descent the whole way, and still leaving a pressure of 70 ft. or 80 ft. above the highest summit of land within the city. The whole length of aqueduct from Loch Katrine to Glasgow is about 34 miles, 10 or 11 of which consist of ridges of very hard rock, forming spurs of Ben Lomond. Through these ridges, in a tolerably straight line, the aqueduct is carried, principally by tunnelling. The tunnels are 8 ft. in diameter, and have a fall of 10 in. to the mile. Across several deep and wide valleys the water is conveyed by cast-iron pipes, 4 ft. in diameter, with a fall of 5 ft. per mile. The average inclination of the whole is 2 ft. per mile. Near Mugdock Castle, about 8 miles from Glasgow, a reservoir has been constructed, 70 acres in extent, and capable of containing 500,000,000 gallons. From this reservoir, the top-water of which is 311 ft. above the sea, the water flows to the city through two lines of cast-iron pipes, 3 ft. in diameter. Of the 26 miles which lie between Loch Katrine and the reservoir, 13 miles are tunnelling, $3\frac{3}{4}$ miles iron piping, while the remainder, where the ground has been cut open, is an arched aqueduct, 8 ft. in diameter, with the same angle of descent as the tunnels. Where the ground has been thus excavated, it has been filled in again over the aqueduct, which is covered throughout, and the surface restored to its original condition.

It will at once be seen from this description that many of the works must be very heavy. There are 70 distinct tunnels, upon which 44 vertical shafts have been sunk. The greatest tunnel, a mile and a half long, just out of Loch Katrine, is worked through the hardest gneiss and mica slate; and five out of the twelve shafts sunk for working it are 500 feet deep. The tunnel just before entering the great reservoir is also a mile and a half long, and is worked in whinstone. In some places, where the mica slate is largely mixed with quartz veins, the rock is so obdurate that the progress did not exceed 3 linear yards in a month, although the work was carried on day and night. In tunnelling the mica slate, the progress was generally 5 yards per month. In drilling

the holes for blasting the rock, a fresh drill or chisel was required for every inch in depth; and 60 drills were constantly kept working at once. There are twenty-five important iron and masonry aqueducts over rivers and ravines, some 60 or 80 ft. in height, with arches of 30 to 90 ft. span.

It was known when the plans were first laid that the hard rock was likely to be free from water, and that, therefore, the working, though slow, would not be retarded by harassing inbreaks of springs. No water occurred in any of the tunnels or workings in mica slate or clay slate. When the works emerged from the slate rocks and entered the old red sandstone, tunnelling was avoided as much as possible; but even in this formation water was met with in much less quantity than had been anticipated.

The works were inaugurated by the Queen on the 14th of October, 1859, when her Majesty and the royal family were *en route* from Balmoral to Windsor. The royal party drove from Holyrood to the Loch, embarked on a small steamer, and went to the mouth of the tunnel by which the water finds its exit, and which was, of course, gaily decked out for the occasion. The ceremony was a very simple one. The Queen turned a small tap, which set in motion a 4-horse hydraulic engine at the mouth of the tunnel, and this raised the great iron shutters which permitted the water to enter the tunnel on its journey of 34 miles to Glasgow. In a few graceful words before leaving, her Majesty said:—"It is with much gratification that I avail myself of this opportunity of inaugurating a work which, both in its conception and its execution, reflects so much credit upon its promoters, and is calculated to improve the health and comfort of the vast population which is rapidly increasing round the great centre of manufacturing industry in Scotland. Such a work is worthy of the spirit of enterprise and the philanthropy of Glasgow, and I trust that it will be blessed with complete success."

With a wise foresight, the corporation provided for a much larger supply than is at present needed. They obtained powers to draw 50,000,000 gallons per day from the lakes, and constructed all the works necessary thereto; but their present actual requirements very little exceed 20,000,000 gallons. Mr. Bateman, the engineer, in a letter to the *Builder*, in 1862, draws attention to the wonderful advantages which have followed the introduction of such a copious supply of pure soft water:—"The saving to the inhabitants in soap, and other articles of private and trading consumption, is estimated at about 40,000*l.* per annum, equal to a free gift to the city of 1,000,000*l.*, being a sum greater than the cost of the whole works. The saving of soap alone in trading establishments, such as bleach and print works, is from one-half to five-eighths of the quantity which was previously used. These facts cannot be too strongly impressed on the minds of the public, as they show the importance and economy of *soft water* supplies.

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